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CLEANING OF BLAST-FURNACE GASES

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THE CLEANING OF BLAST-FURNACE GASES

BY

FREDERICK H. WAGNER, M.E.

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PREFACE

The data herewith presented was prepared with the sole idea of placing before those interested everything of value which has appeared on this subject within the last few years, and to which has been added quite an amount of original research in order to bring the subject up to date. Acknowledgment is hereby accorded to the article prepared by Mr. S. K. Varnes, and presented before the Engineers' Society of Pennsylvania on May 6, 1910; and to that prepared by Mr. W. A. Forbes and presented before the American Institute of Mining Engineers in October, 1913, as well as to other leading articles which have lately appeared in the technical press.

The author would greatly appreciate any suggestions from the readers of this book with the view of extending its usefulness in ensuing editions, and in thus keeping its contents abreast of any developments made in this field of industry.

FREDERICK H. WAGNER

Baltimore, Md., July, 1914

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thought, and as competition all over the world rapidly became of moment, further endeavors to cheapen the cost of production occupied the smelter's mind to such an extent that numerous and costly experiments were entered into in order to determine what further savings could be effected by utilizing this former waste product.

This desire led to the introduction of the gas engine into smelter practice during the last years of the nineteenth century; this introduction of the gas engine did not only lead to the further use of blast-furnace gas, but the use of this gas gave the greatest impetus to the development and improvement of the gas engine itself, as well as to apparatus and methods of cleaning the gas and preparing it for consumption in the engine.

During the early days of this development period it was supposed that the engine would thrive under almost any condition, but it soon became evident that raw, or only partially cleaned blast-furnace gas would not answer the purpose, and consequently all efforts were then directed upon discovering a means for removing all dust and dirt from the gas and thus to properly prepare it for gas engine consumption.

The usual gas from the blast-furnace has the following average composition:

Carbon Monoxide	(CO)	23%
Carbon Dioxide.	(CO_2)	12%
Methane	(CH_4)	2%
Hydrogen	(H)	2%
Water Vapor	(H_2O)	3%
Nitrogen	(N)	58%
	Total	100%

and a heating or calorific value of about 95 B. T. U. per cubic foot. The gas as it leaves the blast-furnace usually contains from 3 to 10 grains of dust per cubic foot of dry gas, but when slips occur this content is considerably increased; this dust content is of a fine gritty texture, and is composed of particles of coke, limestone, and ore, its composition necessarily having a bad effect in hot-blast stoves as well as in boiler furnaces and in the engine cylinders.

In hot-blast stoves bad results are brought about by clogging up the openings between the checker brick, as well as in all chambers proper, and by fusing a foreign mass to the brick-work, thus reducing the cross-section of the flues with a consequent back pressure on the supply. Its effect in the boiler furnaces is to greatly reduce the heating efficiency of the tubes, due to the accumulated dust deposit, and also to close up the passages in the combustion chamber; or in other words, whether used in the hot-blast stove or in the boiler furnaces, the efficiency of either is reduced by a deposit of the dust contained in the uncleaned gas.

This condition then requires a certain amount of gas cleaning, the degree of cleaning being dependent upon the composition of the gas, due to the mixture in the blast-furnace.

If the gas is to be consumed in gas engines, further cleaning will be required, as the presence of even very small quantities of solid matter will be detrimental to the efficient use of the gas in the engine; the bad efficiency thus produced is due to the cutting and scoring of pistons and cylinders by the gritty dust particles, as well as the natural deposit of dust in the cylinders and valve chambers, thus causing frequent shut-downs for the purpose of cleaning and repairs. As stated before, during the early use of the gas engine it was thought that the engine would operate on unclean gas, or on gas only partially cleaned, but a few weeks of operation under these conditions soon proved the fallacy of this presumption.

The gas engine did not become at all reliable until after it became possible to thoroughly cool and clean the gas, and the uncertainty of continuous motive power therefore made it incumbent upon both operator and designer to find some means of accomplishing this in a thorough manner, thus leading to the almost miraculous development of the gas engine during the last twenty years, and which development must certainly be attributed to the advance in the method adopted to clean the gas.

Up until recently the English smelter made practically no attempt to clean his blast-furnace gas, and he usually carried this dust laden product through underground mains directly to the hot-blast stoves and furnaces, with the result that periodical shut-downs were required for cleaning and repairs, these shut-downs necessarily increasing the cost of production because the effective producing period of the furnace was thus limited.

As stated before, Faber du Faur, of Wasseralfingen, was the first to realize the advantage of obtaining clean blast-furnace gas, and his first attempts in Germany to accomplish this consisted in spraying the gas in the mains with water, but the difficulty of recovering and handling the mud thus produced soon became very serious and this method was finally abandoned, except in a few cases where local conditions made its use possible.

Observation soon pointed to the fact that a considerable quantity of dust was deposited in the gas mains at such points where a change in gas direction occurred, or where a difference in the cross-section of the main became necessary, and this immediately led to the introduction of dry separators of various designs; in principle they were all so constructed that the dust was thrown down and collected in the bottom of the separators from whence it was readily removed. A great many schemes were adopted in designing these apparatus, but they all led to the one objective, viz.: to change the direction of the gas and thus to facilitate a deposit of dust, this being greatly aided by a decrease in gas velocity due to the large cross-section of the separator.

The vastness of this gas-cleaning problem can be readily understood when reference is made to the statement of Mr. W. A. Forbes, Secretary to the Coke and Blast-Furnace Committees of the United States Steel Corporation. He states that

> "dust conditions in blast-furnace gas are more severe in the United States than in Europe on account of the larger proportions of very fine ores used in the American furnaces, and on account of the harder driving of the furnaces, which causes more dust to be blown over. As an example of blast-furnace practice in the United States, during the year 1912, ninety-eight of the blast-furnaces of the United States Steel Corporation drew their ore requirements from the Lake Superior district. They produced 13,090,411 tons of pig iron, out of a total of 13,990,329 tons produced by the Steel Corporation during the year. Of the Lake Superior ore used 81.5 percent was Mesaba ore which is physically very fine. There were 1,291,512 gross tons of dust, containing approximately 52 percent of iron, separated from the blast-furnace gas.

"The United States Steel Corporation has installed several plants for briquetting and sintering the dust separated from the blast-furnace gases, with the object of ultimately consuming all the dust in the blast-furnaces. Of 1,291,512 tons of flue dust produced in 1912, 788,933 tons were returned to the furnaces without other treatment than spraying or soaking with water, and the greater part of the remaining 321,430 tons was stocked until such time as it is possible to use the material in some form or other."

Another advantage of prime importance to the smelter is to cool and clean the gas as quickly after its production as is possible, as the smaller volume after cooling reduces the dimensions of the subsequent apparatus and gives the gas to the engines in the smallest compass compatible with the heat units contained. This cooling process however somewhat reduces the sensible temperature of the gas, and therefore calls for a method of treatment which will cool and clean the gas with the least possible loss of heat. The cooling process should do no more than produce a dew point at which all, or practically all of the water vapor is converted into fluid water, this water being then removed by simple mechanical means.

The advantages to be secured by properly cleaning the gas are many, and may be summed up in the following:

(1) The operation of the stoves and boilers becomes more uniform.

(2) Interrupted operations due to the clogging of gas connections are avoided.

(3) The cost of cleaning pipe connections, stoves, and boilers is reduced to a minimum.

(4) The loss of heat due to repeated cleaning of the stoves is avoided.

(5) The useful effect of the hot-blast stove is increased, because the heating surfaces remain clean.

(6) The operation of gas engines becomes regular and positive; the clogging of passages and the rapid wear on the moving parts of the engine is avoided.

The advantages to be secured by cooling the gases are:

(1) The gas volume is reduced, thus decreasing the dimensions of the gas connections and subsequent apparatus.

(2) The gas is dried, due to condensation or removal of the water vapor.

(3) Due to the removal of the water vapor the gas becomes more readily inflammable.

(4) Due to the removal of the water vapor the heating value of the gas per unit of volume is increased.

(5) Due to the removal of the water vapor a higher combustion temperature of the gas is produced, and therefore the transfer of heat to the heating surfaces of the stoves and boilers is accelerated.

(6) The temperature of the blast is increased.

Generally speaking, it would appear almost paradoxical to find it necessary to cool a gas which is to be used for heating purposes, but practice has demonstrated the utility of this proposition; the solution of this riddle will be found in the composition of the gas, where quite a quantity of water is found, this water being drawn into the gas from the water in the atmosphere, in the ore, and in the coke. The burning of wet gas requires that the water vapor in the flame shall be heated to the temperature of combustion, and this alone requires more heat units than are lost in a previous cooling or drying of the gas, as witness the tests at Steelton, where cooling a gas already low in vapor content, because of the loss of sensible heat, caused a serious loss of heat in the process, and it must also be remembered that the temperature of combustion of blast-furnace gas approaches the dissociation zone of water.

The water is entirely, or partially dissociated, and a large quantity of useful heat is thereby immediately removed. This dissociation permits of burning the free hydrogen thus produced, during the further progress of heating, at a lower temperature, with a sufficient supply of oxygen into water again, but this usually occurs in channels or ducts where the heat of combustion can have no effect, thus reducing the efficiency when burning wet gas below what it would have been had the gas been dry, and this in spite of the fact that the specific heat of the dry gas may have been lower than that of the gas in a wet condition.

The cooling of the gas, however, in some cases, adds a disagreeable feature to the process of cleaning, because large quantities of water are required, and in many instances this water must be clarified and used over again; this condition often causes the adoption of expensive cleaning, cooling and pumping apparatus, and this fact might almost suggest dispensing with the cooling apparatus if we were not practically compelled to cool the gas in order to clean it to the required degree.

A great deal of time, thought and money has been expended in an attempt to produce a dry cleaning system which would ensure gas of the required degree of cleanliness, but up to the present time all of these attempts, with the exception of the Halberger-Beth system, have proven to be abortive. Water is the best medium for cleaning the gas to a degree which will comply with the requirements of hot-blast stoves, boilers, and engines, and in selecting any system of cleaning it should be borne in mind that the one which is most readily controlled is the one which should be adopted.

The truth of this statement can readily be seen when it is remembered that one cubic foot of gas at 60° F. and at 30 inches water pressure, when saturated with water vapor will have a volume of 5.7 cubic feet at 200° F., and can carry 1170.68 grains of water vapor. The condensation of this water vapor therefore requires that the gas shall be cleaned by a wet process, and that the temperature of the gas shall be brought as nearly as possible to the dew point in order that it may be dried, because gas at 80° F. can only contain 11.55 grains of water vapor and its original cubic foot at 60° F. will only have increased to 1.056 cubic foot; it must also be remembered that each vapor content has a corresponding dew point below which it is necessary to cool the gas in order to further reduce this vapor content. Positive ignition depends upon the inflammability of the gas, and the dryer the gas the better will be ignition, and the gas can only be dried by proper condensation.

A concise statement of the requirements of a properly designed blast-furnace gas cleaning plant may be summed up into:

(1) The gases must be cooled to as low a temperature as possible in order that the water vapor content may be reduced to the lowest possible minimum.

(2) The gas for heating purposes should contain not more than 0.30 to 0.10 grain of dust per cubic foot.

(3) The gas for engine purposes should contain not more

than 0.005 to 0.01 grain of dust per cubic foot at a temperature of about 80° F.

(4) All apparatus must be simple in construction and positive in operation, and the plant must be so designed as to entail a minimum of labor.

(5) Prime attention must be paid to the cooling of the gas, and the final temperature should be as close as possible to that of saturation in order to avoid any condensation in the pipe connections.

(6) The dry dust catcher, taking the gas from the down-comers, should remove the major portion of the dust content by friction and impingement; and the entire operation of cleaning and cooling the gas should embrace:

(1) A change in volume, causing a deposit of dust content due to a reduction of velocity.

(2) By impingement upon some baffling surface a precipitation of dust content is effected, due to the inertia of the dust particles.

(3) A reversal of flow causes a deposit at the point where this reversal occurs.

(4) Washing, and thus cooling the gas, produces a change of vapor tension, volume, and density, and thus brings about a dew point where the water vapor will precipitate; this change in volume also causes a dust deposit.

The entire operation is usually accomplished in three stages, viz.:

(1) By dry cleaning in the dust catchers attached to the down-comers from the furnace, where the gas is cleaned to a dust content of from 1.5 to 2 grains per cubic foot:

(2) In the primary washing and cooling plant, where the dust content is usually reduced to from 0.10 to 0.30 grain per cubic foot, and

(3) In the final washing plant, where the gas is prepared for the gas engine, and where the dust content is reduced to from 0.005 to 0.01 grain per cubic foot.

Contrary to the general rule, the gas at all plants is not cleaned further than by passing it through dry dust catchers, when it is to be used in hot-blast stoves and boilers only, as is the case at the works of the Pennsylvania Steel Company at Steelton, and of the Maryland Steel Company at Sparrows Point, where in both instances the gas intended for engine consumption alone is accorded further treatment, it being stated that the cooling of the gases at these two plants causes such a loss in sensible heat that cleaning is detrimental.

Data prepared by Mr. A. N. Diehl, of Duquesne,* and presented before the American Institute of Mining Engineers, gives every evidence that the best results were secured in that plant when cleaned gas was fed to the hot-blast stoves. Mr. Diehl further states that the average temperature of the gas from the top of the blast-furnace is about 400° F., and probably 350° F. at the stove burners or at the scrubbers; with Mesaba ores the moisture content will be about 35 grains per cubic foot of gas, determined at 62° F. He gave heat balances in cases where uncleaned gas, containing 3 grains of dust per cubic foot, was burned, and when cleaned gas, containing 0.2 grain of dust per cubic foot and 7.98 grains of water, at 70° F., was utilized, as well as a third case where the gas was sent to the hot stoves saturated with water and at a temperature of 125° F.

As a résumé of the data it may be stated that, per pound of dry gas consumed, clean saturated gas at 70° F. gave an available heat of 79.51 percent; raw or uncleaned gas at 400° F. and containing 35 grains of moisture per cubic foot gave an efficiency of 77.03 percent, while partially cleaned and saturated gas at 125° F. gave an efficiency of 74.33 percent, seeming to prove that the clean gas at 70° F. gave the best results.

According to Mr. Diehl, the use of cleaned gas in the hot stoves effected a saving of $0.1591 per ton of iron, made up by

1 — Better work of the stoves	$0.0998
2 — Saving in lime-stone	0.0072
3 — Saving due to increased production . .	0.0521
Total Saving	$0.1591

which saving was brought about by increased efficiency, heating capacity available, and less labor.

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* See Bulletin of the Am. Institute of Mining Engineers, Dec., 1913.

CHAPTER I

THE THEORY OF CONDENSATION, OR COOLING

THE theory of condensation, as advanced by Dr. W. Feld, of Germany, is a departure from the beaten path hitherto pursued, and is based upon the changes in the condition of the gases which occur when extraneous matter is carried over with the contained vapors, and if the gas is either superheated, or cooled. If, for instance, we take as an example a gas saturated with steam or water vapor, it will be seen that the usual published tables which give the water contents of the gas, only give such water quantities as are contained in a unit volume of given temperature.

According to Dalton's laws, the pressure, and consequently the quantity of a vapor which saturates a given volume are the same for the same temperature, whether this space contains a gas or is a vacuum, and the pressure of a mixture of a gas and a vapor is equal to the sum of the pressures which each would exert if it occupied the same space alone.

Therefore the saturating capacity of a given space for the vapor of any fluid is independent of the presence and nature of any gas contained within the same space, so that a space embracing a volume of one cubic meter and at a temperature of t°, is always capable of confining the same amount of water vapor, no matter if the space is a vacuum, or if it is filled with another gas.

In other words, the amount of water vapor contained in a water vapor saturated gas at t° temperature, and confined in a given space, exerts the same partial pressure which it would exert if it occupied this space alone at t° temperature; or the partial pressure which the vapor of a fluid exerts in a gas saturated with this vapor at t° temperature is equal to the tension of the particular liquid vapor at t°.

The usual tables giving the water vapor contained in a cubic meter of gas at 760 mm. pressure and t° temperature, give nothing more than the weight of the water vapor contents which, corresponding to the tension of vaporization of water at t° temperature and occupying the same space, is compared with the same amount of water vapor saturated gas at the same temperature and in the same space.

In considering the change in condition of a gas it is, however, not only not a matter of indifference but will also lead to a wrong conclusion, if we only determine the water vapor contents in a unit volume of gas at t°. It is therefore of great importance to consider what changes in condition occur during a period of heating and at the same time saturating the volume of gas which, when dry and at 0° temperature and 760 mm. pressure, has a unit volume of 1. In the following paragraphs one cubic meter of gas in a dry condition at 0° temperature and 760 mm. pressure will be designated a "Normal Volume."

In order to determine the change in volume of a gas by heating and at the same time saturating it with water vapors, we have, according to the laws of gases, the following:

According to Gay-Lussac, the volumetric coefficient of expansion α for dry gases is

$$\alpha = \tfrac{1}{273} = 0.00367; \qquad (1)$$

that is, the expansion which the volume V° of a dry gas will undergo when subjected to an increase in temperature of from 0° (its original temperature) to $0^{\circ} + t^{\circ}$, amounts to αt°, and therefore the volume will be V^{t} at t° temperature, or

$$V^{t} = V^{\circ}(1 + \alpha t) \qquad (2)$$

According to Boyle-Mariotte, the volume V of a gas increases or decreases in inverse proportion to the pressure h, or

$$V^{\circ} : V^{t} :: h^{t} : h^{\circ}$$

At the same time, however, the weight of the volume of gas increases or diminishes in the unit volume. One cubic meter of dry air at 0° temperature and at 760 mm. pressure weighs 1.2928 kilogram; if the temperature of the air is increased by 50° C. we have, the pressure remaining constant, the following change in volume:

$$V^{50} = V^{\circ}(1 + \alpha\, 50) = 1.1835 \text{ cubic meter.}$$

That is, 1.2928 kilogram of dry air increased in temperature by 50° C., has a volume of 1.1835 cubic meter, or one cubic meter of this dry air at 50° C. will weigh

$$\frac{1.2928}{1 + \alpha t} = \frac{1.2928}{1.1835} = 1.0924 \text{ kilogram.}$$

The tension of water vapors at 50° C. has been determined by Regnault to be 92.17 mm. As, according to Dalton, the tension of the water vapor at 50° C. is equal to the partial pressure of the vapor in the water vapor saturated air at 50° C., we have the following condition for the water vapor saturated air at 50° C. and 760 mm. pressure:

The total pressure of the mixture is	760.00 mm.
The partial pressure of the water vapor is	92.17 mm.
The partial pressure of the air is therefore	667.83 mm.

At 760 mm. pressure and 50° C. temperature, one cubic meter of dry air weighs 1.0924 kilogram, therefore at 667.83 mm. pressure we only have

$$\frac{1.0924}{760} \times 667.83 = 0.96 \text{ kilogram.}$$

That is, one cubic meter of dry air at 0° temperature and at 760 mm. pressure weighing 1.2982 kilogram has, with no change in pressure but with an increase in temperature from 0° to 50° and with a simultaneous saturation with water vapor, so expanded that one cubic meter of the mixture at 50° temperature and 760 mm. pressure only contains 0.96 kilogram of air, or, from one cubic meter of dry air at 0° temperature we have produced in a water saturated condition at 50° temperature and 760 mm. pressure

$$\frac{1.2928}{0.96} = 1.3466 \text{ cubic meter}$$

of water saturated air.

Let V° = the volume of dry air at 0° and 760 mm. pressure (Normal Volume).

V^t = the volume of water saturated air at t° and 760 mm. pressure.

h^t = the tension of the water vapor at t° (or the saturation pressure of the water vapor at t°).

t = temperature in degrees C.

Then we will have the following equation for the volume of water vapor saturated air at t°:

$$V^t = V^\circ \left(\frac{760}{760 - h^t}\right) \left(\frac{1 + \alpha t}{1.2928}\right) 1.2928 \qquad (3)$$

In this equation the figure 1.2928 (that is, the weight of the dry air at 0° and 760 mm. pressure) should be eradicated, because the coefficient of expansion is the same for all gases; it therefore follows that in the following computations the nature of the gas under consideration will be indifferent. This will then give the following equation for determining the volume V^t of the water saturated gas at t°, referred to the Normal Volume, or

$$V^t = V^\circ \frac{760\,(1 + \alpha t)}{760 - h^t} \qquad (4)$$

and for t° = 50° C., we will have

$$V^{50} = 1 \frac{760\,(1 + \alpha\, 50)}{760 - 92.17} = 1.3466 \text{ cubic meter.}$$

This equation is the reverse of Regnault's formula for determining the normal volume of a dry gas from the volume of the water saturated gas, or

$$V^\circ = V^t \frac{760 - h^t}{760\,(1 + \alpha t)} \qquad (5)$$

As the tension of the water vapor at 100° C. is 760 mm., we will have for t = 100°

$$V^{100} = 1 \frac{760\,(1 + \alpha\, 100)}{760 - 760} = \frac{760\,(1 + \alpha\, 100)}{0} = \infty \qquad (6)$$

Or, one cubic meter of dry gas at 0° temperature and 760 mm. pressure expands through the application of heat, accompanied by a simultaneous saturation with water vapor, and at constant pressure, in such manner that the volume of the water saturated gas at 100° C. (or at the boiling point of water) becomes infinitely large.

If the pressure increases or diminishes, the boiling temperature of the water will increase or diminish, or the temperature at which this final volumetric condition of the water saturated gas occurs is dependent upon the pressure. From this the conclusion is reached that the temperature of a water saturated gas at 760 mm. pressure must always remain below 100° C.

As the weight G of the water vapor absorbed by the normal volume at t° temperature, and the total heat contents of the gas are both proportional to the volume of the water saturated gas at t° C., the volume of the water saturated gas must increase to ∞ at 760 mm. pressure, and at 100° C.

Furthermore, as the heat capacity (that is, the amount of heat which is required to increase the temperature of the normal volume of gas in a saturated condition from 0° to t° C.) of the water saturated gas is also directly proportional to the amount of water vapor absorbed, this must also reach the infinite value ∞ at 100° C. and at 760 mm. pressure.

These changes in condition as applied to water vapors are also true for the vapors of any other liquid and for any gas, therefore Feld draws the following fundamental axioms:

(1) The volume of a gas saturated with the vapors of a liquid will become, if the pressure remains constant, infinitely large at the temperature corresponding to the boiling point of the liquid.

(2) The amount of liquid vapor absorbed by a gas at any stated pressure, and at the temperature corresponding to the boiling point of the liquid, is infinitely large.

(3) The total heat contents of a gas saturated with the vapors of any liquid is, at constant pressure and at the temperature corresponding to the boiling point of the liquid, infinitely large.

(4) The heat capacity of a gas saturated with the vapors of any liquid, at constant pressure and at the temperature corresponding to the boiling point of the liquid, becomes infinitely large.

Therefore in practice the following will hold good:

(5) The temperature of a gas saturated with liquid vapors at any stated pressure, must always remain below the

temperature which corresponds to the boiling point of the liquid.

(6) If a gas, in an unsaturated condition with reference to the vapors of any liquid, and at a stated high temperature, be so treated with this liquid that through the medium of its own heat (heat of the gas) it can saturate itself with the vapors of the liquid in question, it is necessary that at constant pressure the temperature of the saturated gas remain lower than the boiling point of the liquid.

(7) The temperature at which the liquid vapors contained in gas begin to condense (that is, the dew point of the gas for this particular liquid) must at constant pressure remain below the boiling point of the liquid.

Table I gives the changes in the condition of a gas with reference to Volume, Water Vapor Content, Heat Capacity, and Heat Content which, during increase in temperature and simultaneous saturation with water vapor, the Normal Volume, or the volume which at 0° and 760 mm. pressure and in a dry condition amounts to $V = 1$ cubic meter, will undergo.

The values given in this table have been determined from Regnault's values for the tension of water vapors, as well as from the molecular weight (one liter of Oxygen at 0° and 760 mm. pressure weighs 1.4292 kilogram) and the heat of vaporization of the water and of the gas. The heat capacity, column 12, has been determined from an average coal gas, dry at 0° temperature, as being 0.33 calorie per cubic meter. In practice this figure will lead to but a slight and unappreciable error when applied to blast-furnace gas.

The heat capacity of the individual gas which might come under consideration does not vary greatly, the specific heat of air, for example, being 0.237 calorie. As one kilogram of air has a normal volume of 0.77 cubic meter, it follows that the heat capacity of one cubic meter of air is equal to 0.307 calorie. The heat content of dry gas, column 15, is small when compared with the heat content of water vapor (column 14) contained in water saturated gas, column 16. Tables for other simple fluids, not mixtures, can readily be determined, with the aid of Table I, from the tension of vaporization, heat of vaporization, specific heat, and the molecular weight of the fluid in question, or of its vapors.

TABLE I.—CHANGES IN THE CONDITION OF GAS

DETERMINED FOR THE GAS VOLUME WHICH IN A DRY STATE AT 0° AND 760 MM. PRESSURE HAS THE NORMAL VOLUME. V = 1 CBM.

Temperature t	1	2	3	4	5	6	7	8
	Change in vol. which 1 cbm. dry gas at 0° and 760 mm. undergoes at the Temp. t° cbm. $(1+\alpha t)$	Vapor tension of water at t° (saturating tension of water vapor) in mm. Hg. (α Regnault)	1 Cbm. of water saturated gas at t° contains water vapor cbm. $\frac{ht}{760}$	Theoretical weight of 1 cbm. water vapor at t° and 760 mm. Kg. $\frac{0.80464}{1+\alpha t}$ (0 = 1.4292 kg. p. cbm. at 0° and 760 mm.)	1 Cbm. water saturated gas at t° contains water vapors t° Kg. $\frac{ht}{760}\times\frac{0.80464}{1+\alpha}$	Partial tension of gas in water saturated gas in mm. Hg. 760–ht	1 Cbm. gas at 0° and 760 mm. produces at t° when saturated with water vapors cbm. $\frac{760\ (1+\alpha t)}{760-ht}\cdot Vo$	1 Cbm. gas at t° and 760 mm absorbs at t° water: cbm. $\frac{ht\ (1+\alpha t)}{760-ht} = Vt-(1+\alpha t)$
C°	V	ht.	W	Dt.	g.	l.	Vt.	Vw.
–20	0.9266	0.96	0.00126	0.86838	0.001097	759.04	0.9278	0.0012
–10	0.9633	2.159	0.00284	0.83530	0.002373	757.84	0.9660	0.0028
0	1.0000	4.579	0.006025	0.80464	0.004848	755.42	1.0060	0.0060
5	1.01835	6.528	0.00859	0.79013	0.006788	753.47	1.02717	0.00885
10	1.03670	9.179	0.012078	0.77616	0.009374	750.82	1.0494	0.0127
15	1.05505	12.728	0.016748	0.76266	0.012773	747.27	1.0730	0.01795
20	1.07340	17.406	0.022903	0.74962	0.017168	742.59	1.09855	0.0251
25	1.09175	23.546	0.030982	0.73702	0.022834	736.45	1.1267	0.03495

30	1.11010	31.555	0.04152	0.72483	0.030095	728.445	1.1583	0.0481
35	1.12845	41.853	0.05507	0.71307	0.039268	718.147	1.1942	0.06576
40	1.14680	54.970	0.07233	0.70165	0.050750	705.03	1.2362	0.0894
45	1.16515	71.500	0.09408	0.69057	0.064970	688.50	1.2862	0.12105
50	1.18350	92.170	0.12128	0.67987	0.08245	667.83	1.3468	0.1633
55	1.20185	117.77	0.15496	0.66950	0.10375	642.23	1.42223	0.22035
60	1.22020	149.21	0.19633	0.65943	0.12947	610.79	1.5183	0.2981
65	1.23855	187.51	0.24672	0.64967	0.16029	572.49	1.6442	0.40565
70	1.25690	233.79	0.30761	0.64016	0.19692	526.21	1.8153	0.5584
75	1.27525	289.32	0.38069	0.63096	0.24020	470.68	2.0591	0.78385
80	1.29360	355.47	0.46772	0.62202	0.29093	404.53	2.4303	1.1367
85	1.31195	433.79	0.57079	0.61333	0.35007	326.21	3.0566	1.74469
90	1.33030	526.00	0.69212	0.60486	0.41863	234.00	4.3208	2.9902
95	1.34865	634.01	0.83424	0.59662	0.49773	125.99	8.1353	6.78665
100	1.36700	760.00	1.00000	0.58862	0.58862	0.00	....	....

TABLE I.—CHANGES IN THE CONDITION OF GAS—*Continued*

DETERMINED FOR THE GAS VOLUME WHICH IN A DRY STATE AT 0° AND 760 MM. PRESSURE HAS THE NORMAL VOLUME. V = 1 CBM.

9	10	11	12	13	14	15	16	
1 Cbm. gas at 0° and 760 mm. absorbs at t°, water: kg. $\frac{ht. 0.80464}{760-ht.}$ (0 = 1.4292 kg.)	Theoretical volume of Vt. reduced from t° to 0° cbm. $\frac{Vt.}{1+\alpha t}$	Specific heat of 1 kg. water vapor at t° (Mollier)	Heat capacity Vt. in cal. (1 Cbm. gas at 0° and 760 mm. and dry = 0.33 cal.)	Total heat contents of 1 kg. vapor at t° (Mollier)	Heat contents of water vapor G. in Vt. in cal. (g. λ)	Heat contents of dry gas V. at t° in cal. (t. 0.33)	Total heat contents of the water saturated gas Vt. in cal. Kw + Kg = I	Temperature t
G.	V_0^t	Sw.	C.	λ	Kw.	Kg.	I	C°
0.001017	1.00127	0.477	0.330	585.3	0.595	−6.6	−6.005	−20
0.002292	1.00284	0.477	0.331	590.0	1.352	−3.3	−1.948	−10
0.004877	1.0060	0.477	0.332	594.7	2.90	0.0	2.90	0
0.006971	1.0087	0.477	0.333	597.1	4.16	1.65	5.81	5
0.009837	1.01221	0.4772	0.335	599.4	5.89	3.3	9.19	10
0.013705	1.01702	0.4776	0.336	601.8	8.27	4.95	13.22	15
0.018860	1.02343	0.478	0.339	604.1	11.39	6.6	17.99	20
0.025727	1.03198	0.4785	0.342	606.5	15.60	8.25	23.85	25

0.034856	1.04333	0.4792	0.347	608.8	21.22	9.9	31.12	30
0.046893	1.05824	0.48	0.352	611.1	28.66	11.55	40.21	35
0.062737	1.07795	0.481	0.360	613.5	38.49	13.2	51.69	40
0.083562	1.10387	0.4821	0.370	615.8	51.46	14.85	66.31	45
0.11105	1.13800	0.4832	0.383	618.0	68.63	16.5	85.13	50
0.14755	1.1835	0.4845	0.405	620.3	91.53	18.15	109.68	55
0.19657	1.2443	0.4860	0.425	622.6	122.38	19.8	142.18	60
0.26354	1.3275	0.4875	0.458	624.8	164.66	21.45	186.11	65
0.35749	1.4443	0.4892	0.505	627.0	224.15	23.1	247.25	70
0.49460	1.6147	0.4910	0.573	629.2	311.20	24.75	335.95	75
0.70705	1.8787	0.4930	0.675	631.3	446.37	26.4	472.77	80
1.07003	2.3298	0.4950	0.859	633.5	677.86	28.05	705.91	85
1.80870	3.2478	0.4972	1.229	635.6	1149.61	29.7	1179.31	90
4.04918	6.0323	0.4995	2.3425	637.6	2581.77	31.35	2613.12	95
......	....	0.502	....	639.7	......	33.0	......	100

Diagrams Nos. I to IV, inclusive, show some of the values given in the tables for temperatures from 5° C. to 100° C.

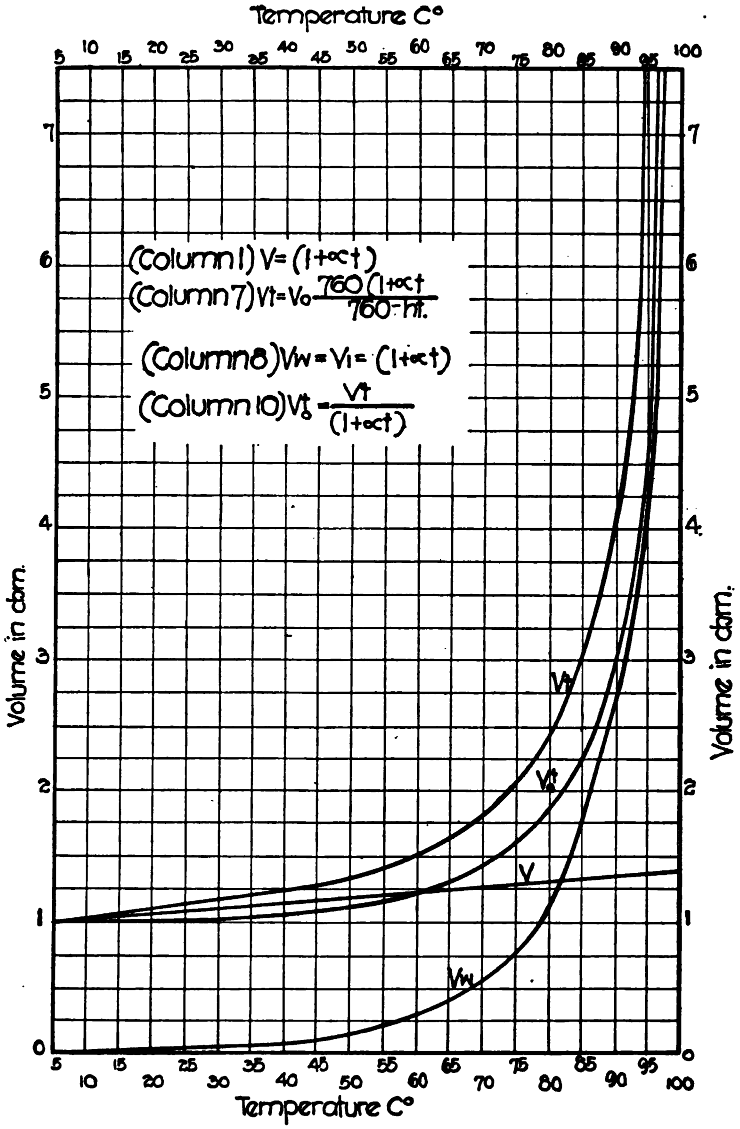


Diagram I.—Change in Gas Volume

Diagram I gives the values for the changes in volume from 5° to 95° C., and refers to columns 1, 7, 8 and 10 in Table I, or

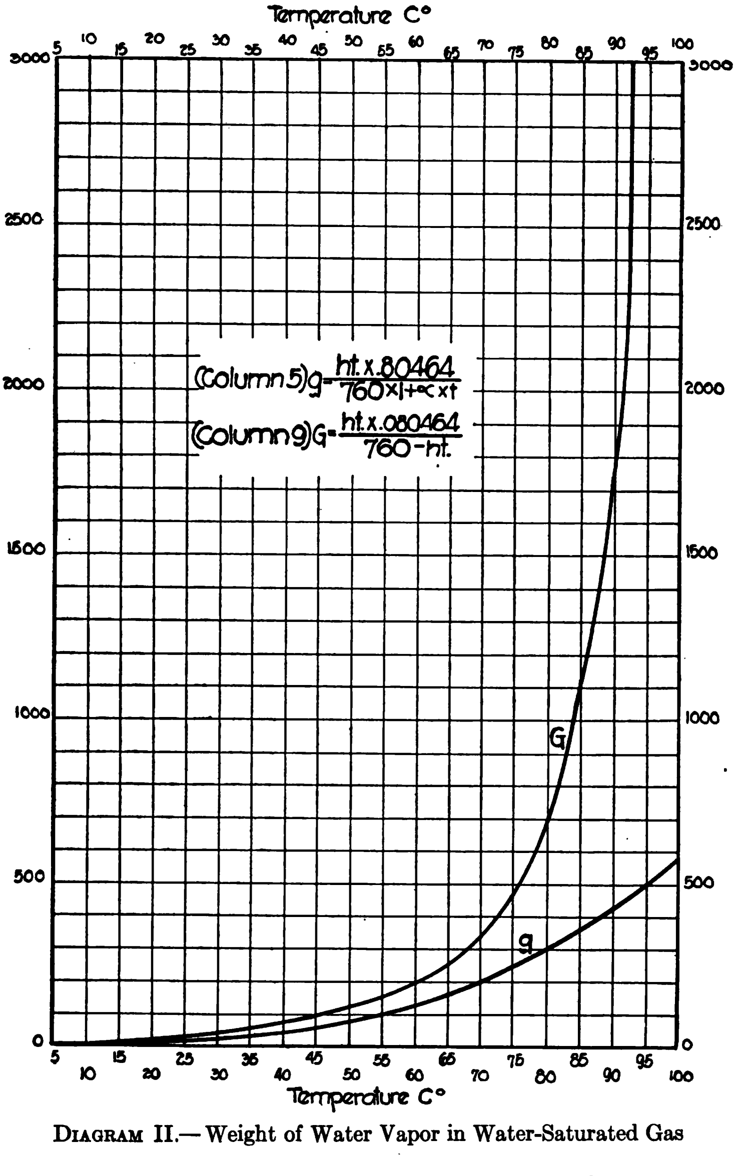


Diagram II.—Weight of Water Vapor in Water-Saturated Gas

Column 1. Change in volume which one cubic meter of dry gas at 0° and 760 mm. pressure undergoes at the temperature t°, or

$$V = (1 + \alpha\, t) \qquad (7)$$

Column 7. Change in volume when one cubic meter of gas at 0° and 760 mm. pressure saturates itself with water vapor at t°, or

$$V^t = V^o \frac{760\,(1 + \alpha t)}{760 - h^t} \qquad (4)$$

Column 8. The amount of water vapor which one cubic meter of gas at t° and 760 mm. pressure will absorb, or

$$Vw = \frac{h^t\,(1 + \alpha t)}{760 - h^t} = V^t - (1 + \alpha t) \qquad (8)$$

Column 10. The theoretical volume of V^t reduced from t° to 0°, or

$$V_0^t = \frac{V^t}{1 + \alpha t} \qquad (9)$$

Diagram II gives the values of the weight of water vapors at temperatures from 0° to 95° C. with reference to columns 5 and 9 of Table I, or

Column 5. The water vapor contained in one cubic meter of water-saturated gas at t°, or

$$g = \frac{h^t}{760} \times \frac{0.80464}{760 - h^t} \qquad (10)$$

Column 9. The weight of water which one cubic meter of gas at 0° and 760 mm. pressure will absorb at t°, or

$$G = \frac{h^t\,(0.80464)}{760 - h^t} \qquad (11)$$

Diagram III shows the values of the partial tension of the dry gas and of the water vapors in water-saturated gas at temperatures of from 5° to 100° C. with reference to columns 2 and 6 of Table I, or

Column 2. The saturating pressure of water vapor in mm. of mercury, according to Regnault = h^t.

Column 6. The partial tension of gas in water-saturated gas in mm. of mercury = l.

Diagram IV gives the values of the water vapors as well as those of dry and of water-saturated gas at temperatures of from 5° to 100° C., and especially for 91° C., with reference to columns 14, 15 and 16 of Table I, or

Column 14. Gives the heat content of the water vapor G in the volume V^t in calories = Kw.

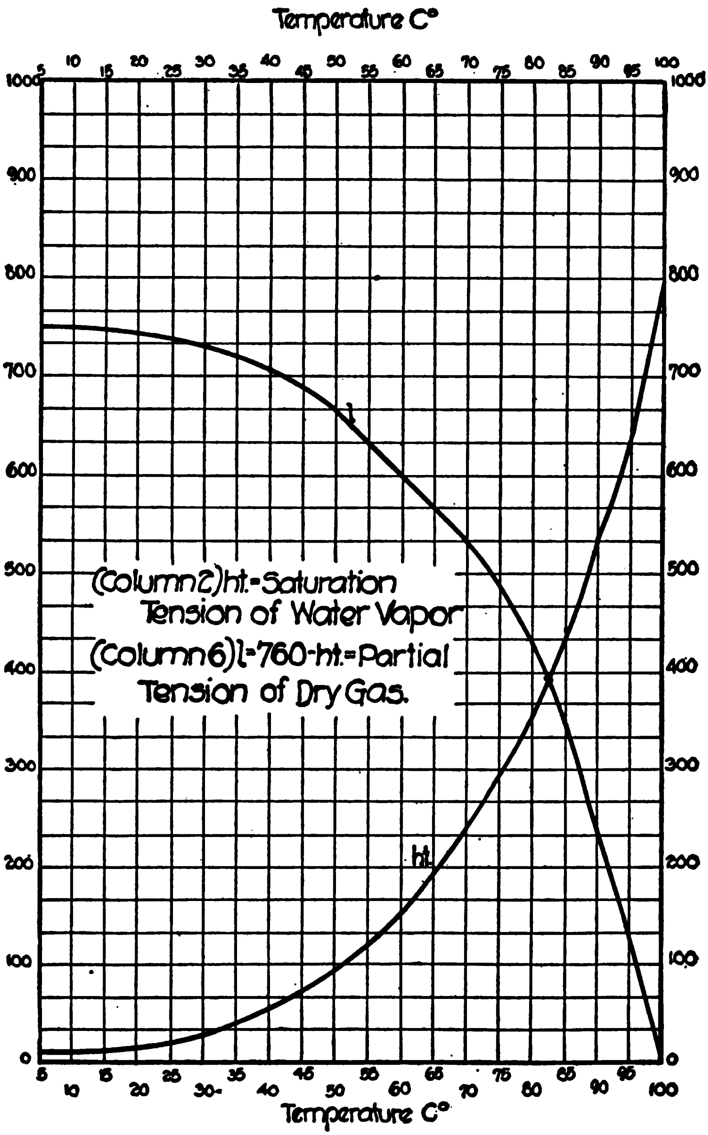


Diagram III.— The Partial Tension of Water-Saturated Gases

Column 15. Gives the heat content of dry gas volume V at t° in calories = Kg.

Column 16. Gives the total heat content of the water-saturated gas volume V^t in calories, = Kw + Kg = I.

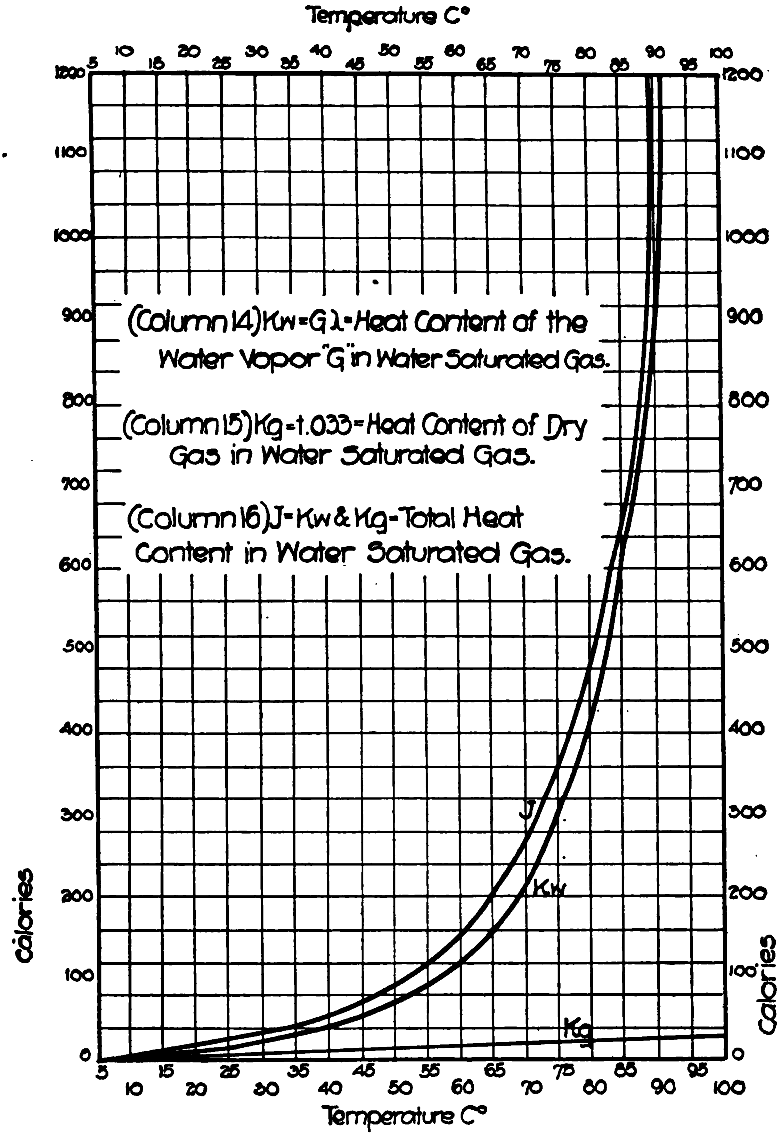


DIAGRAM IV.—Heat Content and Heat Capacity of Water-Saturated Gas

It is also of great importance to note, especially during the period when the gas is being cooled, the changes in condition which occur during the period when the gas passes from the water-saturated condition into the super-saturated condition, and vice versa. The most important changes in condition when dealing with gases will bear upon volume and heat contents. In order to determine the increase in volume during superheating, the volume V^t of the water-saturated gas at t° temperature is reduced to the theoretical volume V_0^t at 0° temperature, or

$$V_0^t = \frac{V^t}{(1 + \alpha t)} \qquad (9)$$

(See the values given in column 10, Table I.)

The theoretical value at 0° temperature thus obtained is, according to the law of Gay-Lussac, multiplied by $(1 + \alpha t)$, and it will then give the volume VT saturated with water vapors at t° and superheated at T°; therefore

$$VT = V^t \frac{(1 + \alpha T)}{(1 + \alpha t)} \qquad (12)$$

If, for example, a gas which is saturated with water vapor at 50° C. and whose volume V^t is 1.3468 cubic meter, is superheated to 100° C. without the addition of any further water vapors, the volume VT at 100° C. will be

$$VT^{100} = 1.3468 \frac{(1 + \alpha\, 100)}{(1 + \alpha\ \ 50)}$$

$$= 1.3468 \frac{1.3670}{1.1835} = 1.5556 \text{ cu. meter.}$$

This gas, saturated with water vapor at 50° C., is now, with reference to its water vapor content, superheated to 100° C. Although this water-saturated gas, which may be heated from 50° C. to 100° with a simultaneous saturation with water vapor, will increase its volume from 1.3468 cubic meter to ∞, the gas saturated with water vapor at 50° C. only increases its volume from 1.3468 to 1.5556 cubic meter while being heated to 100° C. Further, to determine the increase in heat contents during superheating, the heat content It of the water vapor saturated gas at t° is increased by the product of the heat capacity Ct at t° of the water-saturated gas, multiplied by the increase in temperature T − t, or

$$IT = It + Ct\ (T - t) \qquad (13)$$

The following example will serve to explain this:

The heat contents I of water-saturated gas at 50° C. is, according to column 16 of Table I, 85.13 calories, and the heat capacity is 0.383 calorie; by superheating to 100° C. the heat contents increases to $IT = 85.13 + (100 - 50)\ 0.383 = 104.28$ calories. That is, the heat content of the gas saturated with water vapor at 50° C. absorbs through superheating from 50° to 100° only 19.15 calories, or the increase is from 85.13 calories to 104.28 calories, but the heat content of the gas if saturated with water vapor at 100° C. reaches the infinite value ∞.

In order then to consider Feld's fundamental principles, the change in condition which a gas undergoes with reference to its heat contents when it passes from a water-saturated condition into a superheated condition, or vice versa, is of prime importance. The cooling diagram V shows the changes due to cooling, or the change in condition from the superheated state into the water-saturated state, and this is also very important. For example, we will select a blast-furnace gas of usual analysis, because in this gas the terminal temperatures vary considerably, thus showing these changed conditions to more advantage, but the rule will hold good for any other gas.

The curve in Diagram V shows the increase in heat content of one cubic meter of gas, saturated with water, from 0° and 760 mm. pressure to t°. Assuming that one cubic meter of the gas at normal volume and in a dry state contains 62.7 grammes of water, we will find the dew-point (TT) of the gas, as per column 9 of Table I, to be at 40° C. The heat contents of this gas, saturated with water vapor at 40° C., is (see column 16 of Table I) equal to 51.7 calories; if then this gas, which in a dry state at 0° and 760 mm. pressure has a normal volume of one cubic meter, is heated from 40° to 58° C., and heated in such manner that the gas can saturate itself at a temperature above 40° C., the heat content of the gas will increase (in proportion to its absorption of water vapors) 75.6 calories, and at 58° C. it will amount to 127.3 calories, and the water contents will have increased from 62.7 grammes to 175 grammes.

According to column 12 of Table I, the heat capacity of a gas saturated with water at 40° C. is 0.36 calorie; if this gas is heated to above 40° C., without simultaneously saturating itself with water vapor, the gas will be superheated with

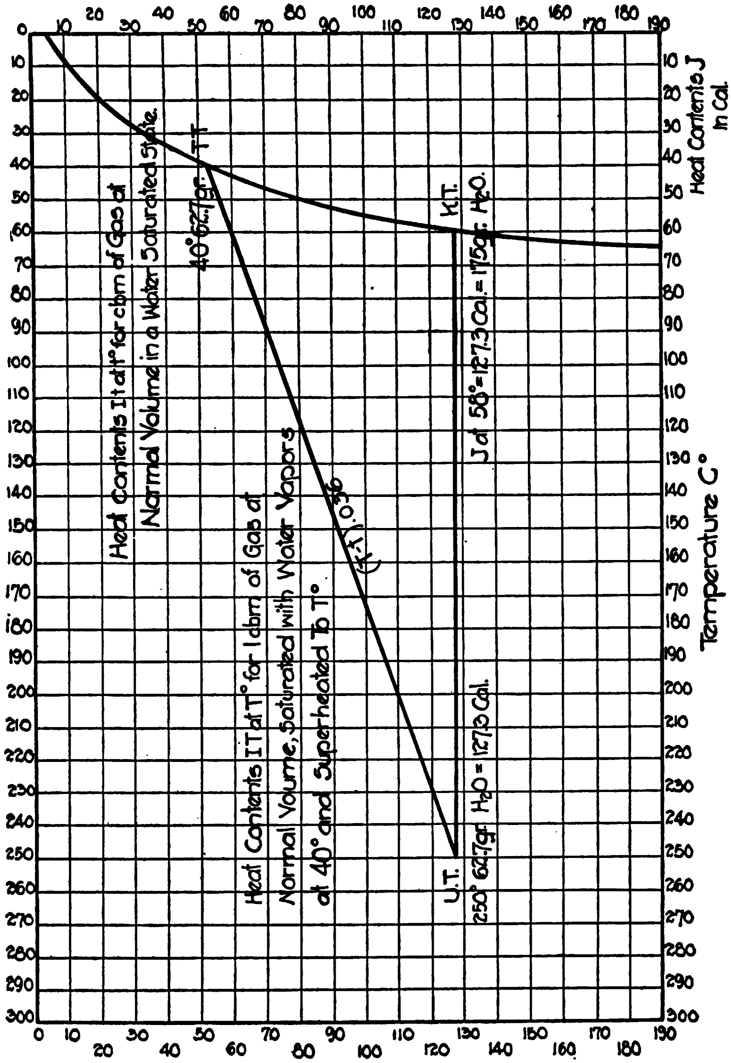


Diagram V.—Cooling Gas Containing Water

reference to its water content, and the heat content will increase 0.36 calorie for every degree of heat, or

$$IT = it + (T - t)\ 0.36$$

In the instance of superheating from 40° to 58° C. with simultaneous absorption of water vapor, the increase in heat content will be 75.6 calories for an increase of eighteen degrees of temperature, but in the last case the increase in heat content of 75.6 calories would correspond to an increase in temperature of

$$\frac{75.6}{0.36} = 210° \text{ C., and}$$

$$T - t \text{ is therefore } 210° \text{ C., and}$$
$$T \text{ is } 250° \text{ C.}$$

The heating of the water-saturated gas at and from 40° C. to 250° C., without the addition of any further water vapor, or the superheating of a gas saturated at 40° C. to a temperature of 250° C., causes the heat content to increase from 51.7 calories by 75.6 calories, giving a total of 127.3 calories, or just as much as if the gas had been heated from 40° to 58° C. with the simultaneous absorption of water vapor.

This higher temperature, amounting to 58° in the above example, Feld terms the "Caloric Compensating Point" (or Compensating Temperature K. T.) for a gas superheated to 250° C. and whose dew point is at 40° C. If now, vice versa, this gas which was superheated to 250° C. and whose dew point for water is at 40° C., is vigorously treated with water, we will, with reference to the superheated condition and the accompanying heat content of the gas of

$$(IT - it) = (T - t)\ 0.36 = 75.6 \text{ calories,}$$

vaporize the water and absorb it in the gas; the temperature of the gas falls from 250° C. to 58° C. in consequence, but the heat content of the gas will remain constant.

The water vapor content of the gas increases from 62.7 grammes to 175 grammes, and 112.3 grammes of water are consequently vaporized; the heat content with reference to superheating, is converted into latent heat, and the fundamental principles given under captions (1) to (7) are then increased by the following:

(8) The heat content of an unsaturated gas with reference to any liquid remains unchanged when the gas, through the medium of superheating heat contained in the gas itself, saturates itself with the vapors of the liquid in question. The

reduction in temperature thus brought about has no bearing upon any reduction in the total heat content of the gas.

Simultaneous with the reduction in temperature during the transition from the superheated to the water-saturated condition, the gas undergoes a reduction in volume. As the values given in Table I are based upon the empirical figures derived from vapor tensions, we cannot readily determine the reduction in volume mathematically, although the error will be but a slight one, but this reduction in volume can be secured by means of diagram V. In order to determine the compensating temperature K. T. for a superheated gas of a given temperature T. the dew point must first be determined; in order to do this the water content of the gas must be known, and this can be determined with the aid of Regnault's formula for Normal Volume. If, for example, the water content is 62.7 grammes per cubic meter at normal volume, the dew point can be taken from diagram II, that is, that temperature at which the water content G of the saturated gas amounts to 62.7 grammes. The dew point in this case lies at 40° C. The volume of the gas at this dew point is then taken from diagram I, or $V^t40 = 1.236$ cubic meter.

If the volume V^t of the superheated gas, at $T = 250°$ C., is to be determined we have equation (12)

$$VT = Vt \frac{1 + \alpha T}{1 + \alpha t}, \text{ or}$$

$$T = 250; \text{ and } VT = V40 \frac{1 + \alpha 250}{1 + \alpha 40}$$

$$= 1.2362 \frac{1.9175}{1.1468} = 2.067 \text{ cubic meters.}$$

The heat content IT of the gas superheated to 250° C. is determined, as stated above, by multiplying the value of the heat capacity at t° (see column 12, Table I) by the increase in temperature above the dew point and increasing the product by the value of the total heat content at the dew point, or

$$IT = It + (T - t)\,C^t \qquad (13)$$

In order (in this case where the heat content amounted to 127.3 calories) to determine the compensating temperature, the relative value It for the value IT of the water-saturated gas is found in diagram IV, and in this case the compensating temperature is found to be at 58° C. The volume of the water-saturated gas at 58° C. is then found in diagram I to be 1.475 cubic meter. From this we have the following:

The volume of a gas whose dew point lies at 40° C. is, in a saturated condition, equal to 2.067 cubic meters at 250° C. Upon transition from the superheated condition into the water-saturated condition, and with a constant heat content, the volume will be reduced from 2.067 cubic meters to 1.475 cubic meter, or through a reduction of 0.592 cubic meter, equal to 28 percent. The volumes therefore are

At the dew point of 40° C.	TP = 1.236 cbm.
At the compensating point of 58° C.	KT = 1.475 "
Superheated to 250° C.	UT = 2.067 "

CHAPTER II

PRIMARY CLEANING

FIRST STAGE: DRY DUST CATCHERS

PRIMARY cleaning, or the removal of the major portion of the dust content from the gas, has as its objective the preparation of the gas for use in the hot-blast stoves, or under the boilers, and also to bring it to such a state of cleanliness that the duty of the final washers in preparing the gas for engine consumption shall be lightened as much as possible.

The necessity of cleaning the gas for hot-blast and boiler use has been disputed in some instances, and this therefore becomes a question the economics of which must be solved in each individual case, the advisability of purifying the gas for this purpose depending upon the relative saving which might accrue by the use of clean gas over the cost of cleaning it.

Mr. S. K. Varnes, Pennsylvania Steel Company, disputes this saving; he states that at the Duquesne works of the Carnegie Steel Company an increase in boiler efficiency of 13 percent was found due to the use of clean gas, and that the efficiency of a hot-blast stove was only 6 percent more with clean gas, giving an increased blast temperature of 150° F. In Europe it has been found that the hot-blast temperature has been increased by 200° F., or 50° more than at Duquesne, by the use of clean gas; but at Steelton an efficiency 1.5 percent lower and a blast temperature reduced by 150° F. was found when clean gas was used. These results seem, and are, contradictory, and the lower efficiency found at Steelton with the use of clean gas was due to the fact that at this plant they had water of from 90° to 100° F. available for use in the scrubbing towers, and the gas left the towers with an average temperature of 100° F., while the moisture content of the gas from the furnace top rarely exceeded 28 grains per cubic foot, and the gas leaving the towers contained about 20 grains of moisture per cubic foot, both measurements being on the basis of gas at 62° F. and 29.96″ barometer. The gas in passing through the towers suffered a loss of 200° in temperature and only eight grains of moisture per cubic foot were extracted, the loss in sensible heat therefore exceeded the saving due to reduction of moisture content, and as a result they secured a lower stove efficiency and lower blast temperature when using scrubbed gas.

If this gas had contained from 40 to 80 grains of moisture per cubic foot, as is common in some practice, and if Steelton had been able to cool the gas to 80° F., the results would probably have approached those coming under Mr. Diehl's observation. The question as to whether it would be of pecuniary advantage or not to scrub the gas for stoves and boilers is therefore altogether dependent upon local conditions of vapor content of the raw gas and the temperature of the water available for scrubbing.

Feeding a boiler with dirty gas results in the deposition of dust and finally fused masses on the boiler tubes, and also in the economizers if these are used, this undesired covering certainly aiding in the non-transference of heat with a consequent loss in efficiency, as the gases leave the boiler setting at a much higher temperature than if the tubes had been clean and the heat in the gas had thus been transferred to the water. If, using dirty gas, the fusing of this material to the walls of the combustion chamber is permitted to continue for any length of time, it will often be found that sledges and bars will be required for its removal with a consequent loss of time in boiler operation, thus further reducing the efficiency by reducing the steaming hours.

Dirty gas in a hot-blast stove retards the rapidity of flame production, and combustion is extended farther through the stove with a possibility of incomplete combustion, or not as complete as with the use of clean gas, thus reducing the mean temperature of the setting with a consequent lower blast temperature. This is but one of the evils, and probably not the worst, because besides impairing the efficiency of the hot-blast stove the dirty gas also causes a reduction in the life of the fire-brick lining, due to the lime carried in the gas combining with the silica of the brick; the ore particles carried forward by the gas soon fuse to the brick-work, thus clogging up the passages and flues, with a consequent reduction in areas. Under these conditions it is certainly recommended that the gas be cleaned for stove and boiler use unless some local reason should exist to recommend the contrary, but whether "wet" cleaners are used in a further stage or not, dry-dust catchers are of universal practice.

The object in primary cleaning is to remove as much dust as possible in a dry manner, or in "Dry Dust Catchers." The large amount of dust deposited in these catchers cheapens and lightens the burden of the subsequent "wet" cleaners, and as the usual wet cleaner requires quite an amount of water, the quantity depending upon the condition, composition, and temperature of the gas, the necessary cooling and clearing of the wash water, if this is to be used again, becomes an expensive proposition, and the proper prior treatment of the gas therefore becomes of prime importance.

The dust deposited in the dry catchers can readily be removed, and as this deposit usually possesses quite an appreciable quantity of iron, it will be highly advantageous to sinter and briquette this stock and return it to the furnace, as was done to a large extent by the United States Steel Corporation in 1912.

The dimensioning of the dry dust catcher is an important feature of its design, and their proper proportions can produce an extraction efficiency of about 80 percent, while their proper action depends upon change in direction of the gas, reduction of its velocity, and sufficient cross-sectional area to permit of separating the dust by gravity.

The original dry dust catcher was an ordinary settling chamber, or a flue of larger cross-section than the gas conduit, which caused a certain deposit of dust due to the change in gas velocity, thus permitting the heavier dust particles to separate by gravity. High velocity carries the dust particle forward, and it is almost impossible to bring the dust particles to a state of rest for a sufficient length of time to permit of their settlement; under these conditions it would be possible to entirely clear the gas of dust particles if the gas were brought to a complete state of rest, but the size of such a chamber would be so vast that its construction would be impracticable.

In proportioning the dimensions of the dry dust catcher, the volume, or cubic contents, should be such that it could contain from 0.75 to 1.5 percent of the hourly production of gas, and if more than one catcher is used the greatest efficiency is secured by placing them in series.

The velocity of the gas in passing through the dry catchers should be from 60 to 120 feet per minute, and the diameter is usually made one-half to one-third greater than the height, preferably the former. The dimensions of the catchers are also dependent upon the character of the ore to be smelted, as very rich ores require smaller catchers than do poor or very fine ores.

In locating the dry dust catcher in the plant every endeavor should be exercised to place them as close to the furnace as possible so as to reduce the length of the down-comer, because the temperature of the gas in the catcher should not be permitted to drop to the dew-point in cold weather, which drop would produce a condensation of water vapor; under this condition the condensation of vapor in the catcher, or subsequent conduit, would carry dust with it, and this dust would eventually be deposited in the conduits in the shape of mud which would soon reduce the area of the gas passage.

If more than one furnace is to be connected to the cleaning plant the gas should be gathered in a common collecting main at the outlet of the dust catchers and then conducted to the subsequent plant, thus in a manner avoiding the troubles due to a fluctuating gas production in the various furnaces, and making the operation of the subsequent apparatus more regular.

The principle upon which the efficiency of the dry catcher is based depends upon utilizing the kinetic energy of the dust particles in order to compel these particles to leave the direction in which the gas is flowing, and this is usually accomplished by admitting the gas at high velocity into the catcher in one direction and then causing it to leave in another direction, while the speed of passage through the catcher is materially reduced.

Another system causes an impingement of the gas against the walls of the catcher, the motion of the gas being momentarily interrupted and the dust thus caused to precipitate. It is also customary to combine these two actions in one machine, and the combined action of change in direction with decreased velocity, and impingement upon some obstruction is of far greater efficiency than would be a simple settling chamber; it should be remembered, however, that this change in direction also produces quite some agitation, and the gas is thus caused to again pick up a certain amount of dust and carry it away, unless the catcher is designed to avoid this.

A description of the usual dry dust catchers is given below; their efficiencies vary, but for some purposes one design lends itself to the accomplishment of a specific object better than another.

Centrifugal Dust Catcher. — The centrifugal dust catcher is of a very simple type, but efficient, its efficiency being usually rated at about 70 percent. This type of extractor is shown in Figure 1, and its construction is such that the gas is caused to enter the vessel in a tangential direction near the top in such manner as to give the gas a rotary downward direction within the vessel. This change in direction causes an impingement upon the walls which, together with the centrifugal motion, causes a deposit of dust, this deposit being assisted by the greatly reduced velocity of the gas due to the large volume of the extractor. In order to leave the extractor the gas must finally take an upward course as the outlet is located centrally in the top. This simple, but effective apparatus combines three of the most essential features of dry dust extraction, viz.: change in direction, impingement, and reduced velocity. The usual construction includes a cone bottom in which the dust is collected, the bottom being provided with either a spectacle valve for the removal of the dust into carts, cars, or other means of transportation, or a pipe of ample cross-section, dipping into a

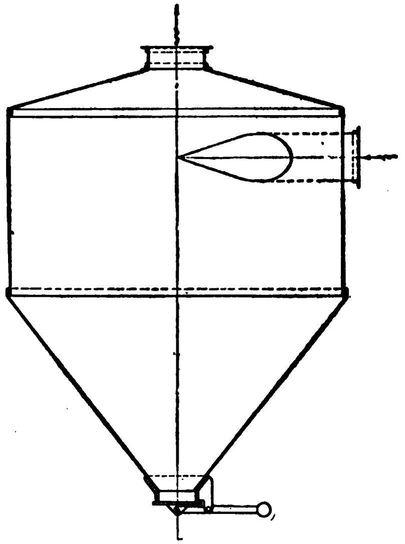


FIGURE 1.— Dry Dust Catcher

water seal, is provided, the deposited dust in the latter case being carried away by a current of water, or it may be removed from the seal pit by any other means.

In proportioning the size of such an apparatus for one blast-furnace producing 2,700,000 cubic feet of gas per hour, the gas containing the average amount of dust, the volume required would be

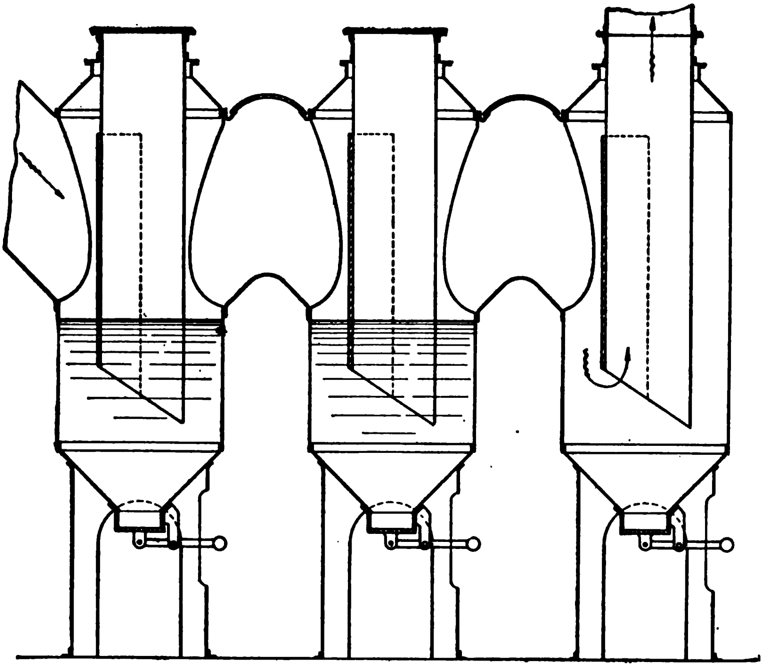


FIGURE 2.—Zig-Zag Gas Connection

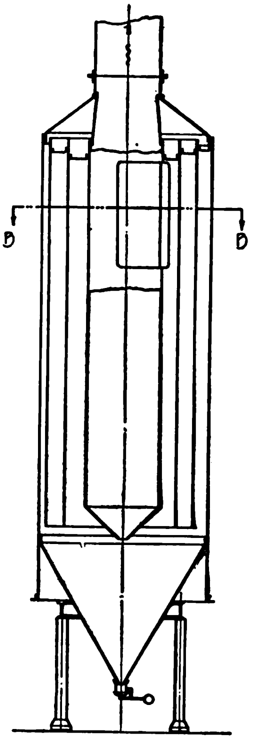
$$2,700,000 \times 0.0075 = 20250 \text{ cubic feet;}$$

this is given by a catcher measuring approximately 35′ 0″ diameter by 20′ 0″ high at the cylindrical shell.

Allowing a speed of about 25 feet per second, the inlet to the catcher should be about 6′ 0″ in diameter, and this speed will then be reduced in the catcher proper to about 0.8 foot per second.

Another method of conducting the gas into the dry dust catcher is shown in Figure 2; instead of the gas entering the catcher direct through the down-comer, this latter pipe is connected to a six-foot diameter zig-zag gas flue, the zig-zag being supported upon cylindrical dust flues, the bottom of each dust flue being provided with a cone ending in a spectacle valve at the discharging point. The final dust flue before the dry catcher, in this case, should be provided with a water sealed outlet pipe to permit of closing off the cleaning plant at any time this might become necessary. Wearing plates, Figure 2, should be provided wherever there is a marked change in direction, and the piping as well as the dust flue should be equipped with manholes to permit of readily replacing these plates.

A system of pipe connections similar to this was described by Mr. H. J. Freyn in the Iron Trade Review of 1910, the operating results from this installation being all that were expected. This zig-zag connection is, however, a refinement which is very expensive and which does not seem necessary, as a properly designed and modern dry catcher will do the same work.



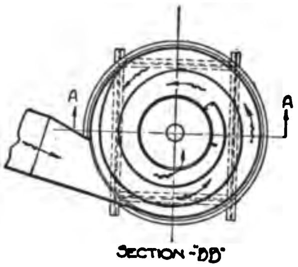
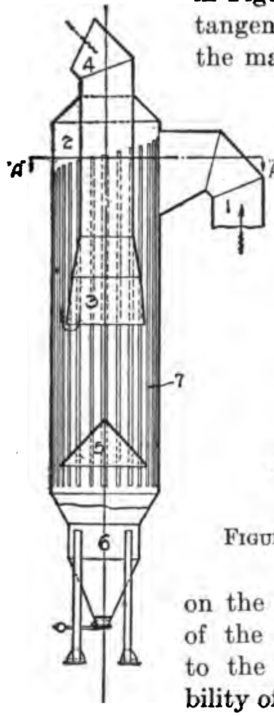


Figure 3.— Dyblie Whirler

Another type of dry dust catcher, known as the **Dyblie Whirler,** and which is a refinement on the simple large chamber described above, is shown in Figure 3. This device consists of a cylindrical shell containing spiral, shell-like inserts, the operative height being about 2.5 times the diameter; the bottom is provided with a cone ending in a spectacle valve, through the medium of which the deposited dust is removed. The gas enters the device on a tangent and passes through same in a spiral direction, as indicated by the arrows in the figure, until it reaches the central vertical tube which connects with the outlet. The principle of operation is dependent upon centrifugal separation of the dust, the latter dropping into the bottom cone, the centrifugal direction of the gas removing all tendencies to agitate and to thus pick up deposited dust and carry it away with the gas from which it has already been removed, as is the case in the simple chamber.

A third device, and one which has been favorably adopted, is known as the **Brassert-Whitting** dry gas cleaner, shown in Figure 4. In this apparatus the gas enters tangentially through the inlet pipe (1) into the main chamber (2) where a whirling motion is imparted to it, the gas thus passing around the annular space between the inner and outer shells. Several Z bars, marked (7), are attached to the inner surface of the outer shell for the purpose of arresting the dust as the gas is impinged upon the surfaces of the bars, and as one flange of the bar is turned in a direction opposite to the flow of the gas, there is little probability of the gas again picking up the deposited dust and carrying it forward. The dust thus separated drops down within the space formed by the bars to the bottom cone (6) while the gas passes under the central flue (3), and up and out at (4). The lower open end of the central flue is provided with a deflecting cone (5); the object of this cone is to prevent the whirling gas agitating the dust in the hopper bottom and thus carrying it forward.



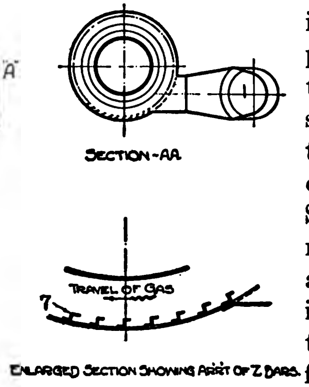


FIGURE 4.—Brassert-Whitting Dry Gas Cleaner

A catcher of this design, or a device such as shown in Figure 3, is far more efficient than the ordinary chamber shown in Figure 1, and it has been stated that three of these

Brassert-Whitting cleaners connected in series have reduced the dust content to less than 0.5 grain per cubic foot; due to this increased efficiency the cubical contents of this cleaner can be considerably less than in the ordinary catcher, and for 2,700,000 cubic feet of gas per hour it is suggested that a volume of

$$2{,}700{,}000 \times 0.175\% = 4725 \text{ cubic feet}$$

be provided. This will be given by a shell 12′ 0″ in diameter and 42′ 0″ high. The inner flue should end at a point equal to about three-sevenths of the total height of the shell above the bottom, or at a point about 23 feet below the top; the diameter of the inner flue should be the same as that of the inlet pipe, or in the above example 6′ 0″; the bottom of the inner flue should be given an enlarged diameter so as to more readily collect the gas.

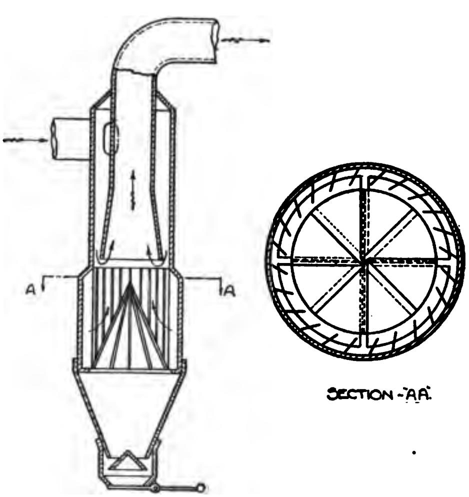


Figure 5.—Brassert Cleaner

The **Brassert** cleaner, a modification of the "Brassert-Whitting" device, is shown in Figure 5. In this case the arresters attached to the outer shell are all below the central flue and are located in an enlargement of the outer shell. The lower portion of the shell terminates in a cone, this cone being provided with a spectacle valve, while the bottom of the dust chamber is supplied with a cone which acts to direct the deposited dust outward and into the bottom of the chamber. The cone directly below the central flue is provided with a number of baffles for catching the dust as the gas enters the central flue, but this latter refinement is of doubtful advantage.

There are many other individual modifications of the above described apparatus, but the differences are slight and are due to the individual experience of the designer, but as a whole these devices serve to depict all of the apparatus embraced in this portion of the field of dry cleaning.

It is doubtful if any of these devices, except in exceptional cases, will clean the gas sufficiently to secure economical results in the hot-blast stoves or boiler furnaces, and even though this were possible, it would still be necessary to condense the water vapor in some manner, and this can only be efficiently performed by the use of some style of wet cleaner, which also greatly aids in removing another portion of the dust.

There are several other dry cleaning systems in operation or proposed, but as these also apply to the final cleaning of gas for engine consumption, they will be described later. I refer to the Cottrell electric discharge system, originated by Dr. F. G. Cottrell, whose patents are owned by the Smithsonian Institute operating through the Research Corporation; the Halberger-Beth system, a modification of the bag house used at the copper and lead smelting plants; the Smith-Bagley system, a modification of the Halberger-Beth; and the Howard Dust Separator; this latter device has, to my knowledge, never been used in blast-furnace practice, but its use has been proposed.

The advantages to be secured by dry-cleaning to as high a degree as possible are many; moving parts, with consequent frequent replacement in some of the high-speed devices, owing to the gritty dust entering bearings, etc., are then reduced in number and for primary cleaning but little more than a condensation of water vapor would be required; but unfortunately no device has as yet been placed in the market which might accomplish the same results in as economical a manner as some sort of moving washer, the static machines being more expensive in first cost and less economical than the washers to be described later.

CHAPTER III

SECOND STAGE: "WET" CLEANING, OR COOLING

I — STATIC CLEANERS

A GREAT many different devices for cooling or condensing have been used in various plants, and numerous attempts at intensive cooling have been made, the original one probably being the attempt to pass gas through large spaces at very slow speed, these spaces being filled with fine sprays of water projected from the top of the device; but it was found that if these attempts were to approach successful operation the spaces would have to be so vast that their construction would be impracticable, and the quantity of water thus required to give efficient spraying would be prohibitive.

The vast cross-section of such a cooler would not permit of a uniform flow of gas over the entire area, with the consequence that dead corners would be formed which would permit the gas to pass through without coming in direct contact with the water sprays; the speed of the falling water in such a case would be so great that sufficient time of contact between gas and water would be impossible, and the efficiency of the cooler would thus be greatly reduced.

A vast improvement and an advance step was accomplished in the operation of this cooler when it became a practice to fill them with coke, stones, or trays, the object being to break up the gas volume into numerous streams and to thus bring these numerous gas streams into contact with the wetted surfaces of the filling material.

Successful cooling or condensation demands that the gas and the water be brought into intimate contact, and this can only be accomplished as explained above, or by a device which will break up the water into minute sprays and so distribute these water globules, or mist, that it would be an impossibility for the gas to pass through the device without becoming thoroughly mixed with the water. This method of cooling, or condensing, is best accomplished in the "Feld," the "Standard Centrifugal," or in the "Acme" washer, or in other washers of this type, an explanation of their operation being reserved for a later chapter.

In the cooling tower as explained above, the trays are so located as to constantly change the direction of the gas flow, and the lower edges of the trays should be serrated in order to provide a uniform distribution of the dripping water onto the next lower lying tray.

As a general statement it may be remarked that the tower coolers are usually circular in shape, made of steel, and provided with internal ledges for the support of the trays; the shells are also provided with explosion discs, and large doors opening onto platforms are supplied for the removal and replacement of trays as well as for cleaning purposes, ladders being provided between the platforms to facilitate attendance. The lower edge of the shell usually dips into a water seal, from whence the dust-laden water is syphoned off. In several European steel works the mud is removed from this seal pit by means of bucket elevators, which convey the mud into cars or other means of disposal.

The Coke Scrubber. — The coke scrubber, as explained above, was the first attempt to produce intensive cooling in an apparatus of this character, but it met very little success. The tower was provided with ledges for the support of trays, which latter carried loosely piled coke, the water sprays attached to the top of the tower sending water trickling through the spaces between the pieces of coke in a downward direction, while the gas passed upward through these same spaces. It soon became evident that the interstices between the lumps of coke would become clogged, thus preventing the flow of both water and gas with the consequent necessity of constant cleaning. The height of the shell was usually made about four times the diameter, but even with very large dimensions the device only presented a very small area, in proportion to the total, for the passage of gas, with the consequence that a great deal of water was entrained and thus necessitated quite a water-separating plant on the gas outlet side. This device was soon replaced by the Zschocke Scrubber.

The Zschocke Scrubber. — This device was originated in Germany, and has been used to almost the entire exclusion of other towers on the European continent, quite a number also being found in America. These towers are built of both a circular and a rectangular, or square cross-section, and the height is usually from 2.5 to 3 times the diameter. At a certain distance below the top of the shell, ledges are placed for the support of the grids, or trays, these grids usually being placed in layers about 4′ 6″ deep, a space of about 18″ being allowed between the bottom of the upper and the top of the next lower lying layer.

The bottom of the shell is usually made conical, as shown in Figure 6, the lower edge of the cone dipping into a water seal from whence the mud is syphoned off. The gas is admitted into the bottom of the tower and passes up through the grids, thus meeting the water sprayed from above; the gas does thus not only come in contact with the water dripping from tray to tray, but it also passes over the wetted surfaces of the trays, which skin contact materially assists the cooling or condensing effect.

The grids are usually made of dressed white pine, the individual slat being 5 inches deep by 7/8″ thick, and the grid bundles are made in sections of a size to facilitate their removal through the doors in the shell. In order to prevent clogging up the openings between the individual slats, or to prevent the flue dust bridging over between the slats, they should be spaced further apart in the lower half of the scrubber than in the upper half, the lower spacing being about 9 inches between slats, and the upper spacing about 6 inches in scrubbers which receive the gas direct from the dry dust catcher, but in the succeeding scrubbers this space may be reduced to 4 inches and 3 inches respectively.

The grids should be so placed that the one set lies at right angles to the next lower one, thus causing a continuous change in the direction of gas flow. The sprays in the top of the tower should be so located that every square inch of tray area receives a proportionate part of water in order to prevent circuiting of the gas through waterless spaces. The sprinklers used are of many different kinds, but one of the most successful is the one described by Mr. H. J. Freyn in the Iron Trade Review of 1910, page 1226.

The Zschocke scrubber, while successful, has several of the disadvantages possessed by the Coke scrubber, but to a lesser degree, in that the entire tower area is not effective for gas passage, due to the grids, thus producing a quicker passage of the gas than would be the case if the grids were removed; and if hot gas is permitted to impinge upon the grids incrustation will necessarily follow unless quite an amount of water above what is required for cooling is used.

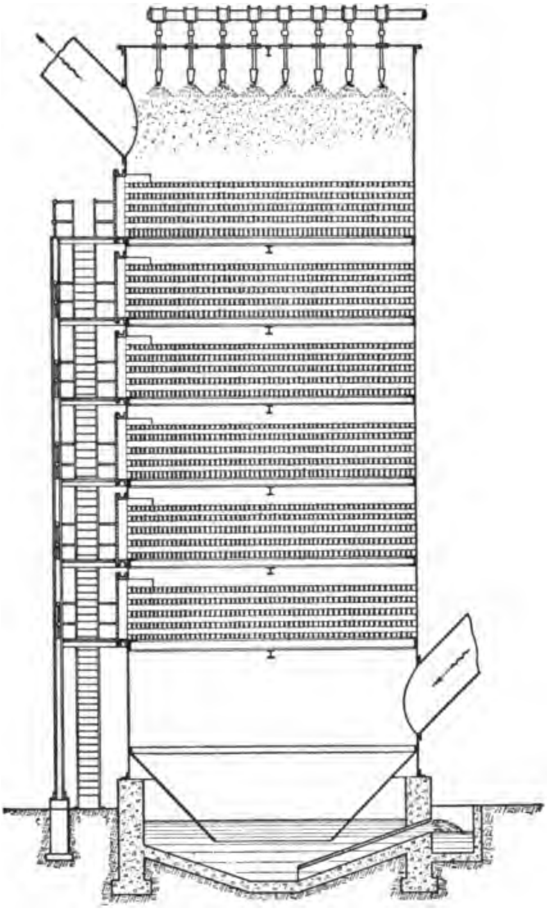


FIGURE 6.—Zschocke Tower

Spray Towers. — These devices usually consist of a plain cylindrical shell provided with an arrangement at the top for uniformly distributing water in a fine spray over the entire area, the gas entering at the bottom and leaving at the top. The differences in the various spray towers only consist in the method adopted for spraying the water, or in the various devices adopted by the designers to break up the water to such a degree as to cause intimate contact with the gas and to fill the entire chamber with spray.

The Steinbart Cooler. — The device used in the Steinbart Cooler for spraying the water consists of a special chamber suspended from the top of the tower, the underside, or bottom, of this chamber being provided with a circular slot extending through about 120 degrees of the circumference; this chamber is supplied with water under pressure, and as the chamber is rotated the water is forced through the slot and spreads out fan shape as it descends through the tower in a helical sheet. A device such as this has but a limited application, as if the tower should be made of any height the water pressure, and consequently the consumption of power at the pumps, would necessarily have to be increased in order to secure the desired effect; besides this, short circuits are possible with consequent hot gas escaping.

The Duquesne Spray. — The Steinbart spraying device was modified at the Duquesne furnaces, and this modification has met with some additional success. This spray, shown in Figure 7, is made of a wrought-iron pipe, the underside of the pipe being slotted; water is fed into this slotted pipe by means of a vertical pipe attached to its center, the vertical pipe passing through a water-sealed gland in the top of the scrubber, thus permitting of rotating the device without the escape of gas. A curved plate of boiler iron is riveted to the horizontal slotted pipe in such manner as to project beneath the slot, the water issuing from the slot running out upon this curved plate, being thus projected into the tower when the device is rotated. To assist in breaking up the water after it has left the spray pipe, the tower is provided at a distance of about ten feet below the rotating pipe with six screens

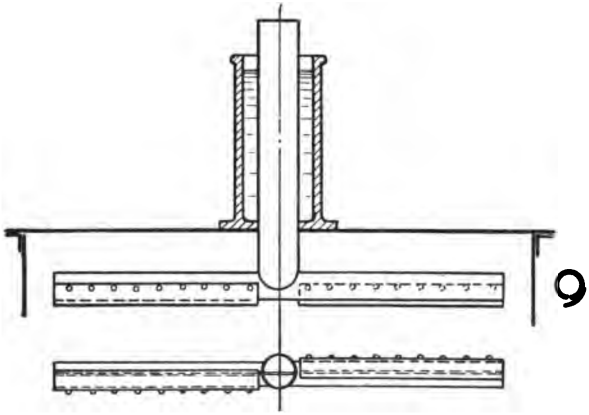
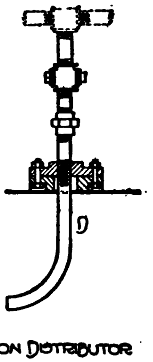


FIGURE 7.— Duquesne Distributor

made up of one inch to one-half inch mesh, these screens effectually breaking up the helical sheet of water coming from the slotted pipe and thus filling the tower with descending drops of water.

The Steelton Spray. — A new type of spray was developed at Steelton after a great many experiments, and its use has been very effective. This device, shown in Figure 8, consists of a horizontal rotating wheel (*A*) having a flat upper surface (*C*), this surface being covered with a $\frac{1}{4}''$ mesh wire screen. About 4 inches above the screen the water finds distribution through fifty-two nozzles (*D*), the water being discharged parallel to the plane of the screen but in a direction opposite to that of rotation. The nozzles are made of $1\frac{1}{4}$ inch wrought iron pipe, the lower end of the pipe being bent through 90 degrees over a radius of about 12 inches, and they are so connected to the top of the tower that any nozzle may be removed from the outside of the tower without interfering with the operation of the device. A 10-inch diameter circular manifold (*E*) supplies water to the various spray nozzles, the distributor being designed to operate under a water pressure of one pound in the manifold. This device seemed to give great promise of effectiveness, and the actual construction has been all that was desired.



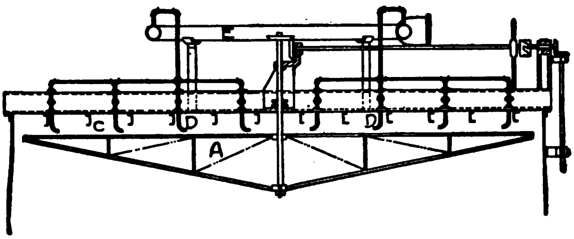


FIGURE 8.— Steelton Distributor

The Duquesne Tower. — Another form of spray tower of recent development and in use at the Duquesne furnaces is shown in Figure 9; this apparatus consists of a steel shell having a height equal to about 6.5 times the diameter, the particular one herewith described being 12 feet in diameter and 80 feet high. This tower is provided with five sets of double screens, the screen sets being spaced about seven feet apart; seven spray nozzles are located under the lower, and the same number of nozzles under the fifth set of screens, the water supply to the spray nozzles being controlled by a specially designed valve located on the outside of the tower; this valve is so constructed with a series of ports and a revolving core that the various nozzles may be shut off successively, thus producing an area of low pressure directly above the closed nozzle.

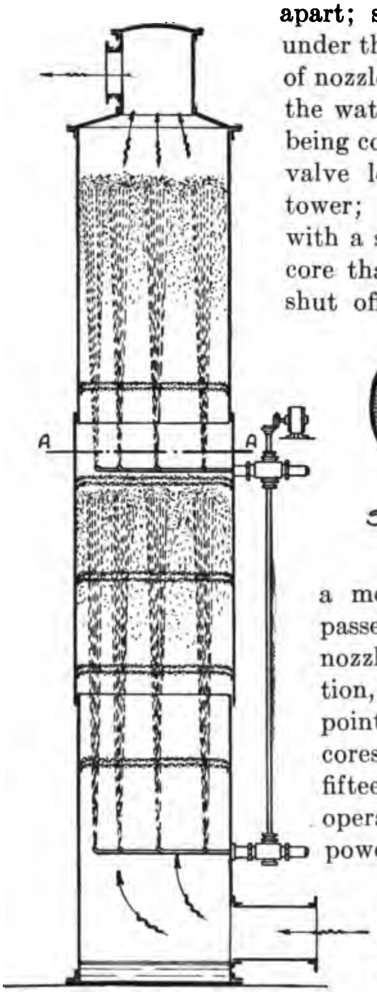
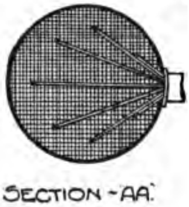


FIGURE 9.—Duquesne Spray Tower



The controlling core of this valve is revolved by means of a motor, and when the core has passed the port leading to the closed nozzle the spray resumes its function, and the gas directly over this point is subjected to a douche. The cores of the valves revolve about fifteen times per minute, and their operation requires about 2.5 horse power.

The screens above the sprays are intended to break up the water into fine drops and to thus ensure intimate contact between gas and water. The gas passes through the tower at a speed of 4 feet per second, and the water at a speed of 60 feet per second under a pressure of 35 pounds per square inch.

It is stated that the cooling effect of this device is very good, the temperature of the gas leaving the tower being only from 5° to 6° F. above the temperature of the water at the inlet, while the moisture content of the gas averages only 0.5 grain per cubic foot above the point of saturation at the temperature of the outgoing gas.

The larger number of spraying towers used in America have no moving parts, while spray nozzles of various kinds are being used to accomplish a complete wetting of the gas; some of these nozzles are very effective, such as the opposed jet spray, but this device requires a water pressure of from 50 to 60 pounds for effective operation, a very serious objection; others, such as the umbrella spray, operate under about 5 pounds pressure, but as their spraying area is very limited a very large number of these nozzles would be required to cover the area of a large tower. The Korting spray is also very effective, but operates under about 25 pounds pressure.

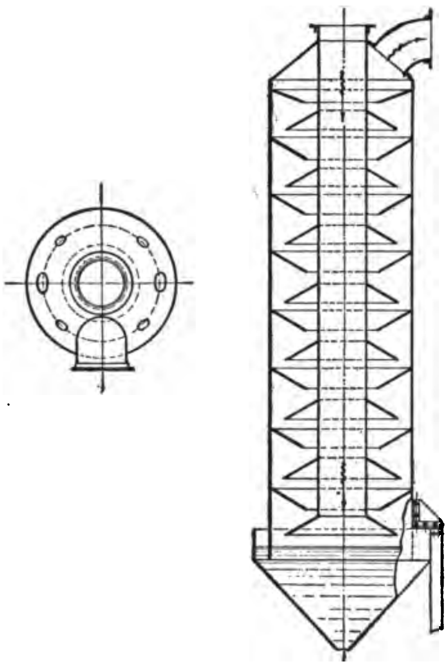


FIGURE 10.—Baffle Washer

In some instances the spray tower is preceded by a Film or Baffle washer, but no great necessity for the additional installation of these devices has been found, as the dry dust catcher supplemented with a properly designed spray tower is sufficient to cool and clean the gases for use under the boilers and in the hot-blast stoves, although the water used in these towers is often in excess of what should be used, and other devices which are under better control than the spray tower have lately been placed on the market for use in their stead.

Film or Baffle Washers. — This washer is usually built in the form of a tower provided with a central vertical flue, a number of cone-shaped deflectors attached to the outer surface of the central flue alternating with inverted deflecting rings attached to the inside of the tower shell, as shown in Figure 10. The gas is admitted at the top of the tower through the central flue, passes down and out from beneath the same, and ascends between the flue and the outer shell, while water is admitted at several points in the top and descends through the gas space in cascades, falling from the shell deflectors onto the flue deflectors throughout the height of the washer, the gas passing through these cascades as it winds its way up through the space between the deflectors, thus bringing about contact between gas and water.

The construction of this device, if built within practical limits, excludes the possibility of a uniform water cascade, thus permitting of short circuits and the consequent passage of gas which has had no, or a very limited, contact with water. In order to avoid this condition more water than necessary for washing is generally used in an effort to close up the short circuit spaces, but even this is of no avail, as the heavier sheet of water at one point will divert the gas to a thinner sheet of water at another point, and the same condition as above is again reached.

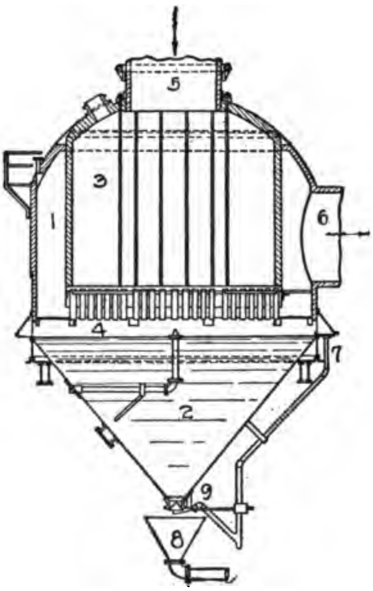


Figure 11.—Mullen Impinging Washer

Impinging Washers. — The object of these devices is to force the gas against a sheet of water in such manner that the heavier particles of dust are driven into the water where they are entrained and settle to the bottom. These devices have a high efficiency as a dust extractor, the efficiency often reaching 90 percent, but as a condenser for removing water vapor from the gas they have proven a failure.

The Mullen Impinging Washer. — This device is shown in Figure 11, and consists of a circular chamber (1), with a cone bottom (2), a circular insert (3) concentric to the outer shell being attached to the top. The outer chamber and cone bottom are filled with water to within a short distance above the top of the cone, and the insert (3) is provided at the bottom with a number of 6-inch diameter tubes (4). The gas enters the device at the top (5), fills the insert (3) and then passes down through the tubes (4), impinging upon the surface of the water in the cone (2); the gas spreads over the surface of the water and rises in the annular space between the outer shell and the insert, leaving the apparatus at (6). The bottom of the cone is provided with a spectacle valve (9) which upon being opened allows the mud to flush into the sewer connection (8); surplus water is carried away by pipe (7), this connection also leading to the sewer, or to the water supply if the water is free of dust.

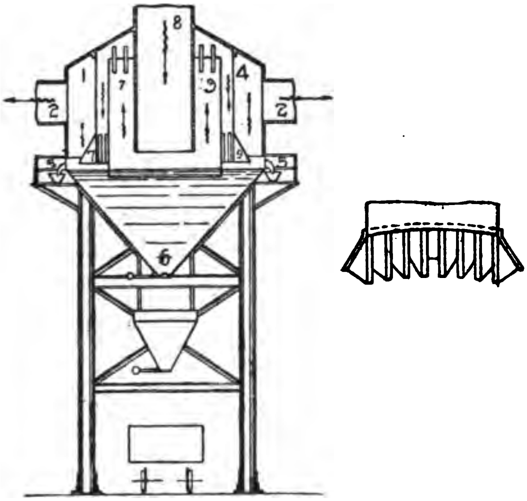


FIGURE 12. — Moyer Impinging Washer

The Moyer Impinging Washer.— The Moyer Impinging Washer is somewhat similar to the Mullen; it consists of a cylindrical shell, marked (1), in Figure 12, this shell having one gas inlet and several gas outlets, usually two, marked (2) in the figure. Two circular concentric shells (3) and (4) are arranged on the inside of the outer shell, the inner one (3) dipping into the water contained in the bottom cone; this cone is provided with several overflows (5) at the upper edge and a spectacle valve (6) at the bottom. The gas enters at (8), passes downwards and impinges upon the surface of the water in the cone. It then reverses its direction and passes up between the central flue and the ring (3), leaving this annular space through the rectangular slots marked (7), passing over and down within the annular space between rings (3) and (4), and again impinging upon the water through the rectangular openings (9), leaving the washer through the outlets (2).

As stated before, these washers can be recommended as dust extractors, but owing to the limited time of contact between gas and water they are not effective condensers or coolers, in fact the moisture content of the gas has been known to increase after passing through this device.

II — SLOW SPEED ROTARY WASHERS

Up to very recent years rotary washers, with the exception of the Bian washer, were not used for primary washing, but the advent of the vertical centrifugal machines has produced quite some progress in this direction. The Bian washer, used in Europe, is the only slow speed machine which has heretofore met with any amount of favor, but owing to its construction it presents many disadvantageous operating conditions, especially in this country where the blast furnaces are pressed to a much higher production and where the operating conditions are more severe than in Europe.

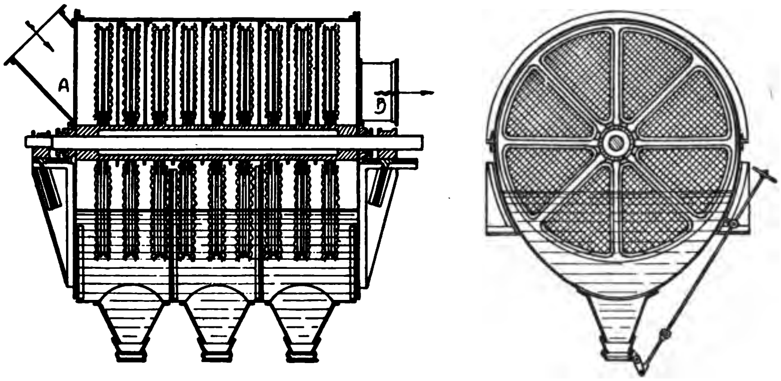


Figure 13.— Bian Gas Washer

The Bian washer, shown in Figure 13, consists of a stationary horizontal cylinder made of steel, a shaft, to which are attached a number of discs made of fine wire mesh, passing through the center of the cylinder, while nearly the entire lower half of the discs dip into the water contained within the shell. The gas passes through the cylindrical shell from the inlet nozzle at (*A*), leaving the device at (*B*); the revolving screens carry a film of water up with them as they revolve, and as the screens are but very little less in diameter than the washer shell, the gas is compelled to pass through the fine mesh in order to find egress, thus coming into intimate contact with the water film. The disadvantage of this device consists in the large loss in pressure through the screens, and the clogging up of the perforations if the gas be hot.

The Bian washer is made in three sizes and requires the following power and water consumption for their operation:

Furnaces of 100 tons capacity per day, 740,000 cu. ft. of gas per hour 82 H. P.

Furnaces of 150 tons capacity per day, 1,110,000 cu. ft. of gas per hour 113 H. P.

Furnaces of 200 tons capacity per day, 1,480,000 cu. ft. of gas per hour 144 H. P. and from 22 to 25 gallons of water per 1000 cubic feet of gas, the gas being cooled to about 10° C. above the temperature of the water at the outlet.

III — MEDIUM AND HIGH-SPEED WASHERS

The first high-speed cleaning device put into operation was probably the ordinary centrifugal fan, the fan casing being provided with several nozzles for injecting water into the gas. The fan was also the model for the present disintegrators, because the fan blades pick up the water in conjunction with the gas and dash them jointly against the casing, thus bringing water and gas into intimate contact, a difficulty arising, however, in the limited time of gas and water contact, which limitation does not permit of proper dust settlement, and if fans are used at least three of them must be placed in series in order to ensure any degree of efficiency; the first one evaporating the injected water by contact with the hot gas, resulting in a gas and water mixture, the other two acting as condensers for the water vapor, thus wetting and precipitating the dust, while the entrained water must be removed in a final water separator. The power required for these fans with water injection is excessive, one instance under the author's observation recording a consumption of 50 horse power with no water injection and passing 1,765,000 cubic feet of gas per hour, while with an injection of 2 liters of water the power consumption increased to 180 horse power.

The Feld Vertical Centrifugal Washer. — This device, depicted in Figure 14, consists of a number of washing chambers mounted one above the other, the bottom of each chamber being provided with two or more gas ports (1); a vertical shaft, suspended from a roller bearing (2) mounted on the top of the dome, is provided with a series of frustums of cones (3) in each chamber. These cone sets are of two designs, the one shown in Figure 14 having each cone perforated at the top for the emission of water, the other method being as shown in Figure 15, where only the outer cone is perforated. The dome is provided with a perforated diaphragm which acts as a water separator, this diaphragm (4) consisting of a revolving, perforated steel plate, the entrained water being precipitated when the gas passes through the perforations during its passage to the outlet. The gas enters at (5), passes through the ports (1), and finally leaves the washer at (6); the wash water enters the top chamber at (7) and overflows from chamber to chamber through the gas ports (1).

The lower edges of the cones dip into the wash water and, as the shaft revolves carrying the cones with it, the water is picked up and ascends along the inner surface of the cones, being hurled out in a tangential, horizontal direction through the perforations. With the cones as shown in Figure 15, the water passes out over the top edges of the inner cones and is then broken up by passing through the perforations of the outer cone. In this manner most intimate contact is occasioned between the gas and the water, as it is impossible for any particle of gas to pass through the washer without being thoroughly wetted.

In the largest size washer built at present the vertical shaft makes 100 revolutions per minute, and under ordinary conditions the machine throws no back-pressure whatever, although they are sold with a guarantee of a maximum back pressure of not more than 2 inches of water. The rated capacities of the washer can be increased by about 30 percent with a slight increase in back pressure.

In primary cleaning the Feld washer acts both as a cleaner and a condenser, the upper portion of the washer being the condenser and the lower portion the cleaner, the hot water descending from the condenser sections being the active dust extractor; therefore the Feld washer, as a primary cleaner, can take the gas at any top temperature, the number of cooling chambers being arranged accordingly. It is a well known fact that to properly remove dust from gas the entire

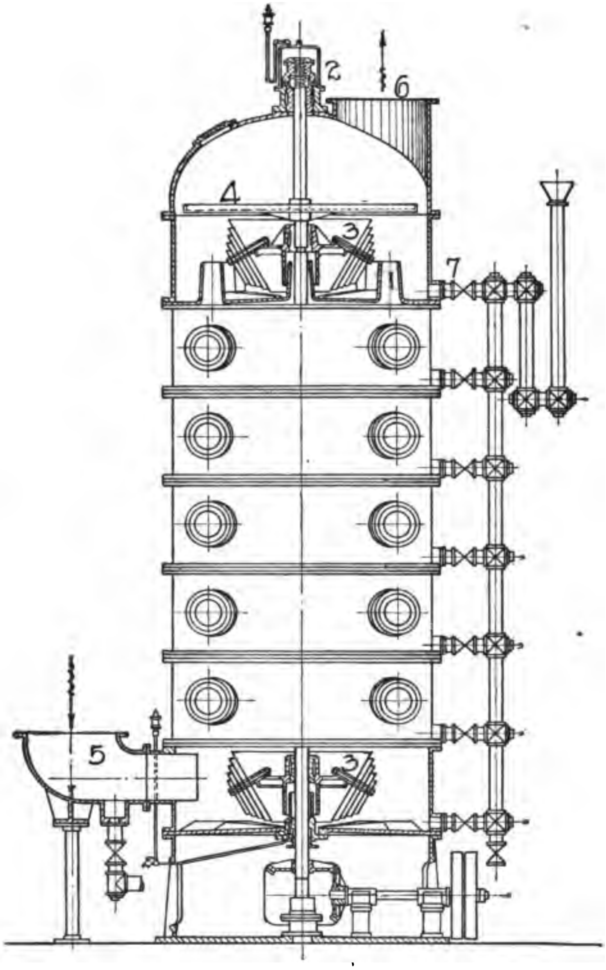


FIGURE 14.—Feld Centrifugal Washer

dust particle must be thoroughly wetted, and as it ascends and meets the heavier water particles it becomes weighted and falls to the bottom; this is the action in the Feld washer, where the gas enters at the bottom and leaves at the top, the water taking the counter direction. It is also well known that if cold water is thrown upon an impalpable powder the water will form globules upon the surface of the powder, while if hot water is added to the dust an emulsion instantly takes place; this is taken advantage of in this device, as when the wash water from the condensing sections reaches the washing sections it has a temperature which causes it to act with greater efficiency than if it had been cold.

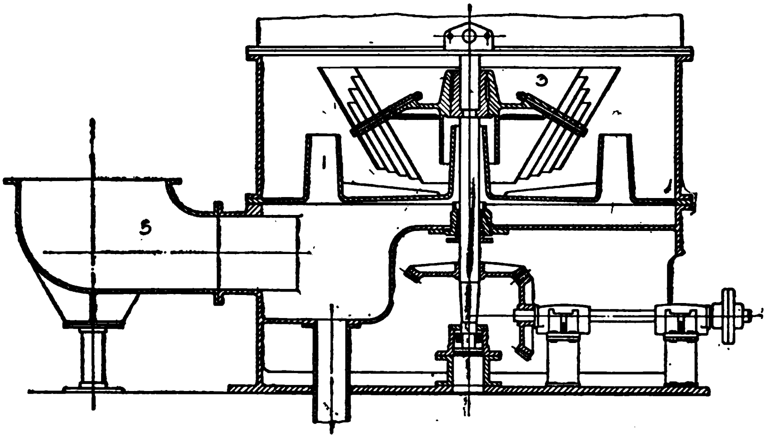


FIGURE 15.— Inlet Section of Feld Washer

It is claimed that this device embodies the following six principles in the one machine, and which principles are universally acknowledged as necessary to completely separate dust from gas, viz.:

(I) **Cooling.** — The gas upon entering the washer is intimately mixed with sufficient water to lower the temperature to the desired point, thus altering its volume, density and vapor tension, producing a dew point at which the water held in suspension is precipitated.

(II) **Impinging.** — The gas upon entering the washer impinges upon the water spray, which in turn throws it against the sides of the washer, from whence it impinges upon the wetted surface of the bottom of the next chamber.

(III) **Centrifugal Action.** — The gas is subjected to centrifugal action in that when it comes in contact with the water thrown out by the revolving cones, it is whirled about in each successive washing chamber, due to the water leaving the cones at a tangent and carrying the gas with it; this centrifugal action can best be estimated when it is stated that the water leaves the cones with a periphery speed at the edge of the cone of 1580 feet per minute.

(IV) **Change of Flow.** — The direction, or flow, of the gas is constantly changed, in that the whirling water carries the gas with it in a circular direction, after which it passes upwards and then at right angles to the upward flow across the partition plate; then up through the gas ports to have this cycle repeated in the next chamber.

(V) **Velocity.** — The velocity of the gas is changed as many times as there are chambers to the washer, the gas being contracted at the ports and expanded in the chambers; in a ten-foot diameter washer the speed of the gas through the ports is at the rate of 42 feet per second, and in the washing chambers at the rate of nine feet per second.

(VI) **Filtering and Washing.** — The gas is passed through a most minute spray of water, the water thus acting as a filter. No better washing effect can be produced than is that due to the water delivered by the cones; the water is so finely divided that it entirely surrounds and wets the dust particles, weighting them and causing them to drop.

The power required by this washer is a minimum when compared with others, and as the device is also used as a final cleaner for engine gas, the entire washing and cooling plant with the Feld apparatus permits of a most practical design, and one that entails a minimum of labor, power, and water consumption.

As the Feld washer is a device new to America, it may be well to mention the following results claimed at Pompey, France, with washers on primary service but with only four washing chambers. The usual construction of the washer for primary cleaning embodies seven chambers, the upper three acting as coolers and the lower four as washers. The Pompey plant was placed in operation in May, 1910, and operated continuously, 24 hours per day, for more than two years without a shut-down for cleaning or repairs.

The quantity of gas produced at Pompey per ton of iron varied from 4200 to 4500 cubic meters at 0° C. The gas leaving the furnace contained from 15 to 25 grammes of dust per cubic meter, and was first treated in a dry dust separator, where the dust content was reduced to from 3 to 10 grammes per cubic meter, the temperature of the gas entering the Feld Washer being from 120° to 150° C.

The amount of water vapor present in the gas varied between 80 to 125 grammes per cubic meter, according to the humidity of the air and to the materials charged to the furnace. The following figures give the gas volumes at the different temperatures and the quantity of water required for cooling, both for the maximum and minimum temperatures of the gas and for the maximum and minimum water vapor content. The gas volumes give the increase of the normal volume (one cubic meter at 0° and dry) at the various temperatures.

Gas temperature at washer inlet................	150° C.	120° C.
Water vapor per cubic meter of gas in grammes ..	125	80
Theoretical dew point at	52° C.	45° C.
Actual dew point at	58° C.	52° C.
Volume of gas at inlet temperature	1.57 cbm.	1.40 cbm.
" " " " actual dew point	1.50 cbm.	1.37 cbm.
" " " " outlet temperature	1.10 cbm.	1.10 cbm.
Inlet temperature of water	15° C.	15° C.
Outlet temperature of water	47° C.	40° C.
Heat absorbed per liter of water	32 Cal.	25 Cal.
Theoretical quantity of water per cbm. of gas ...	3.55 liter	3.00 liter
Actual quantity of water per cbm. of gas	3.62 liter	3.06 liter

These washers at Pompey require from 15 to 20 horse power each, and as the gas pressure is low at times fans are used to transport the gas, each fan requiring 35 horse power for its operation, making the total average power when the fans are used 55 horse power, or 0.0374 horse power per washer per 1000 cubic feet of gas, and only 0.0136 horse power per 1000 cubic feet per washer when the washers are operated without the fans, and in most cases this would be possible in America owing to the high top pressures from the furnaces, and as the pressure lost in passing through the washers is about nil as a rule.

The actual amount of water used to reduce the temperature from 150° C. to 26° C., and to reduce the water vapor content from 125 grammes per cubic meter to but 2.83 grammes above the theoretical point of saturation at 26° C., was 3.62 liters per cubic meter, while theoretically 3.55 liters were required, the actual result coming as close as is practically possible to the theoretical requirement.

The design of an entire Feld cleaning plant is such that the apparatus occupies a minimum of space, and it is claimed that its arrangement is such that a general supervision of and easy access to each individual piece of apparatus is possible, and in contradistinction to the usual plant seen in America the Feld plant is arranged to avoid all periodic interferences with continuous operation.

As constructed at present we find the usual plant subject to numerous cleaning periods for the gas mains as well as for the cleaning apparatus, which periods entail serious interruptions to continuous operation. It is claimed that this condition has been completely overcome by the arrangement adopted for both the washers and the pipe connections, and the periodical cleaning of the settling basins, entailing a considerable expenditure of labor and money, is entirely obviated; this is accomplished by the method adopted to automatically concentrate the mud in the clearing basins and the continuous disposal of the concentrated mud by mechanical means, thus also reducing the labor to a minimum.

The entire plant is placed at a sufficient elevation above the ground line to permit of the overflows from the various machines to empty into the clearing basin, the cleared water to run into a sewer, or to be pumped back into the washers, and the mud overflows from the clearing basin to empty into the mud concentrators and from thence to the mud pumps by gravity, all pumping inside the plant being thus avoided.

As an example of design, we will assume a plant capable of cleaning the gas from two furnaces, the gas from each furnace amounting to 2,700,000 cubic feet per hour (76,487 cubic meter), or 45,000 cubic feet (1275 cubic meter) per minute at a temperature of 250° F. (120° C.).

By referring to Figure 16, it will be seen that the gas from the furnace, and after having passed through a dry catcher, enters the hydraulic main (*A*) of the washing plant; in order to avoid any periodical cleaning of the horizontal stretch of gas main (*A*) from the dry dust catcher to the washer (*B*), this stretch of the main is formed into a dip, or the lower, open edges of the main dip into the water seal (*C*). The dust, which may be separated from the gas by friction during its passage through this main, is deposited in the trough (*C*), which is filled with warm running water at all times, and the resultant mud, in a concentrated form, is automatically carried off through the syphon overflows (*r*) to the mud trough (*a*) and from thence to the cone basin (*H*), where the mud receives a further degree of concentration.

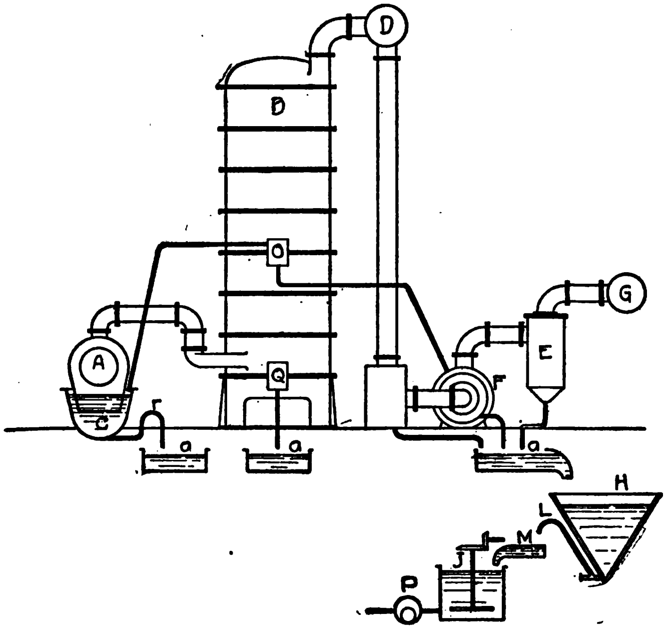


Figure 16.—Diagram of Feld Washing Plant

A reduction in the active cross-section of the inlet pipe by the deposit of dust or mud on the inner surface, and a consequent loss of pressure, is thus avoided; the periodic interruption caused by necessary cleaning, as well as the usual disagreeable condition produced by contact with dust or mud during such periods when the usual type of gas main is being cleaned, is also avoided; besides this, the hydraulic main provides a sufficient safety valve during a possible explosion in the furnace.

The gas is now admitted into washer (*B*), where it is cooled and cleaned, the dust content being reduced to 0.10 grain and less per cubic foot, dependent upon conditions; the gas is cooled to about 77° F. from an inlet temperature of 250° F. and with a water vapor content of 53 grammes per cubic foot; it is possible, however, that the gases may enter the washer at a higher temperature, and the higher the entering temperature of the gas the better will be the effect of dust washing, no additional water being required due to this higher temperature unless the water vapor content should increase in proportion.

At the inlet nozzle of the washer the hot, saturated gases immediately come in contact with hot water in the lower washing chamber, whereby the temperature of the gas is brought to the compensating temperature K. T., which in this case will be at about 57° C. (135° F.), the unit volume of the gas being thereby reduced. All primary washers, designed to cool and clean the gas, as stated before, are provided with three lower cleaning chambers, one intermediate, or separating chamber, and three upper cooling chambers.

The three lower chambers are supplied with hot water, this water having been heated in the upper cooling chambers by contact with the gas, the temperature of the water changing with the sensible heat of the gas, depending upon its entrance temperature and water vapor contents.

In the upper, or cooling chambers, the gas coming from the washing chambers with a temperature of about 57° C. (135° F.) is cooled down to 25° C. (77° F.); here again the final temperature is dependent upon the sensible heat of the gas, and upon the temperature and amount of cooling water used. The quantity of water required for cooling the gas is admitted into the top cooling chamber, this water extracting heat from the gas by condensation and precipitation of the water vapor; about one-fifth or one-sixth of this hot water is admitted into the lower washing chambers, where its temperature is increased from about 50° C. (122° F.) to 60° C. (140° F.).

The hot water coming from the overflow (*O*) under the cooling chambers, and which water contains but little dust, passes into the trough (*C*) under the inlet main (*A*), serving as a seal for the gas main and as a carrier for any dust deposited at this point. This water finally passes into the cone basin (*H*) by means of the syphon (*r*) and the mud trough (*a*). The hot water which leaves the washer at (*Q*) contains the major portion of the dust washed out of the gas, or about 90 percent, and it flows directly into the cone basin (*H*).

The cooled and primary cleaned gas now passes through the collecting main (*D*), and from thence down to the exhauster (*F*) and water separator (*E*), which in turn delivers it to the primary gas main (*G*) for transfer to the hot-blast stoves and boilers. The exhausters are only supplied and operated in such cases where the top pressure is too low to permit of a maximum drop of 2 inches of water pressure in passing through the washers.

If it should be desired to clean the gas for engine consumption, it would have to be subjected to final, or minute cleaning, which would require an additional washer to take the gas from the primary clean gas main; this latter washer would only be provided with four washing chambers, cooling chambers no longer being needed, and the connections would be so arranged that the necessary amount of engine gas could be diverted from the main (*G*) into the final washer.

The entire mud-bearing water is conducted into the cone basin (*H*) for concentration; experience has shown at Pompey and at other works that these cone basins are sufficient for the purpose, but if further concentration should be required, apparatus can be added for this purpose, as will be shown later. The time required for clearing the water is dependent upon the nature of the dust and upon the temperature of the washing water, and therefore upon the temperature of the gases.

The mud-bearing water is distributed over the entire area of the cone basin (*H*) by means of a serrated weir placed at one end; the mud, owing to the slow flow of water through the basin, is deposited at the bottom, and the cleared water passes out on the opposite end and is either pumped back into the washer, or it is run into the sewer.

The deposited and concentrated mud is automatically carried off by the overflow (*L*) into the collecting trough (*M*), from whence it flows by gravity into the agitators and collecting tanks (*J*) if further concentration is required, otherwise it is led to a final depository; these agitators are supplied with centrifugal mud pumps (*P*), and the outflow to the pumps is so arranged that there is no suction, the pump only being required to force the mud to its final depository. If more than one collecting tank (*J*) is required, these tanks are interconnected by means of overflows, the agitators being for the purpose of preventing a settlement of the mud after the clear water has been drawn off, and during pumping periods.

As stated above, the gas to be cleaned amounts to 45,000 cubic feet (1275 cubic meter) per minute at 250° F. (120° C.) with a pressure of 10 inches of water, while the dust in suspension amounts to about 2.2 grains per cubic foot (5 grammes per cubic meter), and the water vapor in the gas is 53 grains per cubic foot (120 grammes per cubic meter.)

CHANGE IN THE PHYSICAL CONDITION OF THE UNPURIFIED GAS

From the above figures it is readily seen that it first becomes necessary to determine the volume of the gas when it is reduced to 0° C. and 760 mm. pressure, and dry. This also demands that the temperature be determined to which the gas must be cooled and at which it begins to condense, or give up its water; this temperature is the dew point of the gas for water.

Secondly, it is necessary to determine the changes in condition which occur to one cubic meter of gas at 0° C. and dry, and at a pressure of 760 mm.; or we will determine:

(*a*) — the condition of the gas in a water-saturated state at the established dew point;

(*b*) — the condition of the gas when superheated to the given maximum temperature of 120° C.; and

(*c*) — what changes in condition occur during the process of cooling and cleaning.

The given maximum amount of water (120 grammes per cubic meter) corresponds to a dew point of 52° C.; if then one cubic meter of dry gas at 0° and 760 mm. pressure is heated to 52° C., and if it is simultaneously saturated with water, the volume will be

$$(a)\quad V^t_{52} = \frac{1 + 52\alpha}{760 - ht} \times 760 = 1.375 \text{ cubic meter,}$$

in which ht = the tension of the water vapor at t° C., as given in column 2 of Table I, and

$$\alpha = \text{the coefficient of expansion of gases} = \frac{1}{273} = 0.00367.$$

In order to determine the volume in a superheated condition at 120° C., it is first necessary to determine the theoretical volume (V^t_o 52, column 10, Table I) of the water-saturated gas at 52° C. reduced to 0° C. (see diagram I), or

$$V^t_o\, 52 = \frac{V^t\quad 52}{1 + 52\alpha} = \frac{1.375}{1 + 52\alpha} = 1.155 \text{ cubic meter,}$$

and from this we can determine the volume of the gas in its superheated condition at 120° C. (see column 1, Table I), or

$$(b)\quad V^t\,120 = V^t_o\,52\ (1 + 120\alpha) = 1.155\ (1 + 120\alpha) = 1.66 \text{ cbm.}$$

The heat capacity of the water-saturated gas at 52° C., determined from 0° and 760 mm. pressure (see column 12 of Table I) amounts to 0.389 calorie per cubic meter; at 120° C. the heat contents, determined from 0° and 760 mm. pressure (see columns 14 and 15 of Table I, or diagram IV), with $KW + Kg$ at 52° C., amounting to 95.5 calories per cubic meter, will therefore be

$$95.5 + 0.389\ (120 - 52) = 95.5 + 26.5 = 122 \text{ calories,}$$

or, a gas with a dew point at 52° C., due to its water vapor contents of 120 grammes, and which is superheated to 120° C., possesses a total heat value of 122 calories when referred to its water contents.

As soon as this gas is intimately treated with water it passes from a superheated into a water-saturated condition, and therefore, according to cooling diagram V, the temperature is reduced to the equalizing temperature K. T., that is, it falls to that temperature at which the total heat in a saturated condition equals the total heat of the superheated gas, or it possesses 122 calories.

The heat required for superheating is converted into latent heat by the evaporation of water; according to diagram IV, the total heat of 122 calories per cubic meter (at 0° and 760 mm. pressure) in a saturated condition corresponds to a temperature of 57° C., and therefore the compensating temperature K. T. will be at 57° C.; that is, upon entering the washer the superheated gas is immediately brought into such intimate contact with the wash water that the temperature is at once reduced from 120° C. to 57° C., during which temperature reduction the gas passes into a condition of water saturation.

It must be noted, however, that in spite of this reduction in temperature from 120° to 57° C., and which reduction of course varies according to the temperature of the gas and its original water contents, the total heat remains at 122 calories, no further heat being extracted from the gas at this point, a most beneficial effect; but as the temperature is reduced to 57°, and as the gas becomes saturated with water, there is a corresponding change in gas volume, and the volume of this water-saturated gas will be

$$V^t_{57} = \frac{1 + 57\alpha}{760 - h} \times 760 = 1.46 \text{ cubic meter,}$$

or a reduction in volume upon entering the washer of from 1.66 to 1.46 cubic meter, or about 12 percent.

The washer is so constructed that the gas in the three lower or washing chambers maintains this equalizing temperature K. T., in this case 57° C.

The gas is next cooled in the upper, or cooling sections of the washer, and the water used should be of such quantity and temperature as to permit of cooling the gas down to 25° C., in which case we have

$$V^t_{25} = \frac{1 + 25\alpha}{760 - h} \times 760 = 1.126 \text{ cubic meter,}$$

this cooling of the gas therefore again reducing the volume by about 23 percent, and the gas enters the exhausters at this volume.

From the above data the gas volume for each furnace at 0° C. and dry, is computed as follows:

The unit volume, according to the above, is 1.66 cubic meter at 120° C in a superheated condition; if there are 1275 cubic meters of gas at 120° C. from each furnace to be cooled and cleaned per minute, the total volume at 0° C. and dry per furnace will be

$$\frac{1275}{1.66} = 770 \text{ cubic meters per minute,}$$

or 46,200 cubic meters, equivalent to 1,630,860 cubic feet per hour per furnace, instead of 2,700,000 cubic feet carrying water at 120° C.

It must be noted that the assumed water content of 120 grammes per cubic meter is taken as a maximum from practical observation, and although in some cases it may be exceeded, it is usually only reached during the winter months, or while using a very wet coke or ore; as an average condition it would perhaps be correct to figure on a water content of 80 grammes per cubic meter, equivalent to 35 grains per cubic foot. In such case the gas volume would be considerably less, but in order to determine the dimensions of the apparatus the maximum condition should be assumed.

The washers in this case should then have a capacity for the two furnaces to treat

$$1{,}630{,}860 \times 24 \times 2 = 78{,}281{,}280 \text{ cubic feet}$$

of gas per day at 0° C., and by reference to the table giving the capacity of Feld washers it will be seen that three washers having a diameter of 10 feet, or the H_1 size, will be required.

GAS VELOCITIES

As seen above, the amount of dry gas at 0° C. and 760 mm. pressure is 770 cubic meters per minute, but the main from the dust catchers must carry the original volume of gas, or

$$770 \times 1.66 = 1275 \text{ cubic meters}$$

at a temperature of 120° C., or 90,000 cubic feet per minute, for the two furnaces. As the main (*A*) is connected to one furnace at each end, two down-comers will be required, one for each furnace, and, allowing a speed of 27 feet per second in the down-comer, a cross-section of

$$\frac{90000}{2 \times 60 \times 27} = 28 \text{ square feet}$$

will be required in each of the two pipes entering the hydraulic main, or each of these pipes should have a diameter of 6 feet.

The cross-section of the hydraulic main to accommodate these two feeders would be

$28 \times 2 = 56$ square feet, or a diameter of 8 feet 6 inches.

In the primary gas main, which collects the cooled and cleaned gas coming from the washers, the temperature of the gas will be 25° C., and coincides with a unit volume of 1.126 cubic meter; the total volume of the gas here will be $770 \times 1.126 = 867$ cubic meters, or 3,672,600 cubic feet per hour for two furnaces, and with a speed of 27 feet per second the cross-section of this main would be

$$\frac{3,672,600}{60 \times 60 \times 27} = 38 \text{ square feet,}$$

requiring a pipe diameter of seven feet.

COOLING WATER REQUIRED

As stated before, the amount of cooling water required to reduce the temperature of the gas from 120° C. to 25° C. is determined from the total heat in the gas; at 120° C. the total heat of the superheated gas was found to be 122 calories per cubic meter, and at 25° C. the total heat of the cooled gas is about 24 calories (see column 16 of Table I); therefore $122 - 24 = 98$ calories must be absorbed by the water.

Assuming that the water has an inlet temperature of 20° C. (68° F.) and that the water is heated in the washer chambers to 50° C. (122° F.), there would be required $\frac{98}{30}$ = say 3.27 liters of water per cubic meter of gas, or in round numbers 3.50 liters of water, and the total quantity of water consumed per 1000 cubic feet of gas would then be 24.8 gallons.

This amount of cooling water is based upon the maximum water vapor contents of 120 grammes per cubic meter and for the given temperature of 120° C.; with a mean water content of 80 grammes per cubic meter only 80 calories would have to be absorbed, but in this case the water would not be heated to 50° C., only to 48° C., and somewhat less water would be required.

DETERMINATION OF MUD VOLUME

As seen from the statement above, the total amount of cooling water with a maximum saturated condition of the gas amounts to 3.5 liters per cubic meter of gas; of this amount the only portion which takes up very much dust is that which flows from the lower washing chamber; this overflow amounts to about 0.6 liter per cubic meter of gas (or about the same amount of water which is claimed for the Schwarz-Bayer disintegrator to be described later, and which seems to prove that this latter machine does not condense the water vapor burden in the gas), or 4.75 gallons per 1000 cubic feet of gas; the other overflows, which carry a lower dust content, coming from the cooling chambers and gas main carry the remainder of 2.9 liters of water.

The amount of gas to be treated per 24 hours (at 0° C. and 760 mm. pressure) is 46200 × 24 = 1,108,800 cubic meters, or 2,217,600 cubic meters for the two furnaces, and the heavy mud-laden water from the lower washing chambers will be

$$\frac{2{,}217{,}600 \times 0.6}{1000} = 1331 \text{ cubic meters per 24 hours,}$$

while the cleaner overflow water from the cooling chambers will give

$$\frac{2{,}217{,}600 \times 2.9}{1000} = 6431 \text{ cubic meters per 24 hours;}$$

and as the total amount of dust in the gas is 5 grammes per cubic meter, we will have a total of

$$\frac{2{,}217{,}600 \times 5}{1000} = 11{,}088 \text{ kilograms of dust in 24 hours.}$$

The mud-laden water from the cleaning chambers contains about 90 percent of the extracted dust, or about 9600 kilograms in 1331 cubic meters of water, or about 7.22 grammes of dust per liter of overflow; this is concentrated to about one-third in the cone basin (*H*), or it is reduced to a sludge amounting to 444 cubic meters in 24 hours; therefore one liter of water coming from the bottom of the cone basin will carry 21.7 grammes of dust, or every gallon of water will contain about 1337 grains of dust.

The overflow water from the cooling chambers contains the remaining 10 percent of the dust extracted, or 1045 kilograms, 4.8 grammes having been removed per cubic meter;

this dust will be found in the 6431 cubic meters of water per 24 hours, or about 0.165 gramme per liter of water.

This water is concentrated in the hydraulic main (*A*) by clearing to about one-fifth, that is, it is reduced to about 1282 meters of dust-laden water in 24 hours. These 1282 cubic meters are further concentrated to about one-fifth in the cone basin (*H*), or to 256 cubic meters of concentrated mud water in 24 hours; one liter of this water will then contain about 4.125 grammes of dust.

It is therefore necessary to pump away from the cone basins $444 + 256 = 700$ cubic meters of concentrated mud water every 24 hours, or about 30 cubic meters per hour, and the centrifugal pumps must be proportioned accordingly.

The cone basin in this case should be about 100 feet long, 40 feet wide, and 15 feet deep, embracing 30,000 cubic feet of space.

The two agitator tanks, if such are required, should each have a capacity of about 900 cubic feet and the agitators should make from 10 to 15 revolutions per minute, and the three mud pumps (one being in reserve) attached to these tanks should each have a capacity, allowing for all contingencies, of about 18 cubic meters, or 635 cubic feet per hour.

As will be seen from the above, the Feld system is based upon the special arrangement and efficiency of the Feld washer, this machine cooling and washing the gas in such manner that the primary washing is practically completed before the gases are cooled down. The efficient action of the Feld washer permits of the execution of these two operations with a consumption of never more than 10 percent above the theoretical quantity of water required, while if the gas is to be cleaned for engine consumption the final washers will only require about two gallons of water per 1000 cubic feet of gas.

In designing a plant the power allowed for primary washing, including fans, water pumps, transmission and washers, is about 2.4 horse power per 1000 cubic meters, or 0.068 horse power per 1000 cubic feet of gas, and for final washing 0.6 horse power per 1000 cubic meters, or 0.017 horse power per 1000 cubic feet, or almost double the power actually required at the Pompey plant.

Table II gives the capacities of Feld washers for treating blast-furnace gas with a maximùm back pressure of two inches of water, but they usually operate with an even gauge on both inlet and outlet; these capacities can be increased by 30 percent with a slight increase in back pressure.

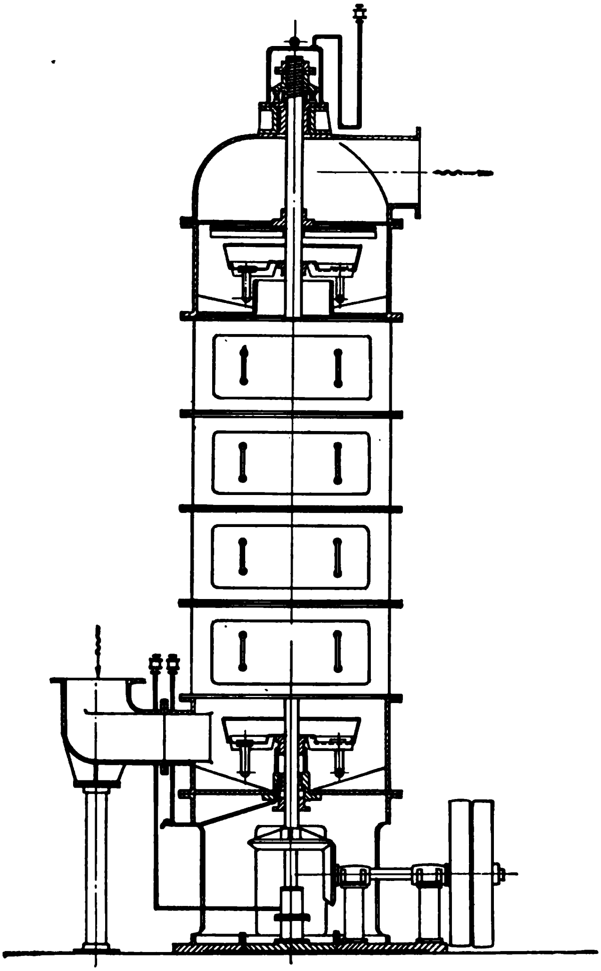


FIGURE 17. — Standard Centrifugal Washer

Standard Vertical Centrifugal Washer. — This device, shown in Figure 17, is somewhat similar to the Feld, but instead of outer gas ports the bottom of each chamber is provided with a central gas passage, and the cones are replaced by a basket, the outer surface of the basket being perforated; the water is picked up by the bent tubes attached to the bottom of the basket and forced through the perforations by centrifugal pressure. This washer is effective for various operations, but it cannot be made of as large a capacity as the Feld, and to my knowledge it has never been used in cleaning blast-furnace gas.

TABLE II

CAPACITIES AND DIMENSIONS OF FELD WASHERS

Washer number	H_1	H_2	H_3	H_4	W_1	W_2	W_3	W_4	W_5
Capacity in millions of cu. ft. per 24 hrs.	45	30	20	12.5	6.5	4.5	2.0	1.0	0.5
Corresponding volume of gas at 30° C. or 86° F.	35	22	14.5	10	5.5	3.3	1.6	0.85	0.4
Corresponding volume of gas at 15° C. or 59° F.	30	20	13.3	9	4.5	3.0	1.5	0.75	0.36
Corresponding volume of gas at 0° C. or 32° F.	29	19	12.5	8.5	4.0	2.8	1.4	0.70	0.35
Diameter of washer	10′ 0″	9′ 0″	8′ 0″	7′ 0″	6′ 0″	5′ 0″	4′ 0″	3′ 0″	2′ 6″

Reco Centrifugal Washer. — This washer embodies impingement with washing effect, and its construction is shown in Figure 18; in its design it consists of an outer cylindrical casing, the open bottom of the casing being sealed in water; the casing is provided with an inner tube the lower edge of which is serrated, the tube extending down to within a few inches of the water in the seal, a revolving, inverted cup being placed over the top end of this tube. The inner surface of the outer casing is provided with deflectors extending around the entire circumference, while the inverted cup is supplied with horizontal shelves and the inner tube with projecting vanes. The shaft within the tube is also provided with vanes, the shaft being suspended from a bearing in the top of the washer.

The hot gas enters the washer at (1) and is deflected downwards, impinging upon the water in the seal, evaporating a portion of this water and carrying the vapors forward. The gas then passes up the central tube (2), where both gas and water vapor are subjected to violent agitation through the vanes (3) mounted on the hollow shaft (4). The gas now enters into the inverted cup (5), passes down the annular spaces, and rises between the cup and outer casing; water from the sealed stuffing box flows down upon the top of the cup, from whence it is hurled out by centrifugal force against the walls of the outer casing, flowing down the concentric deflectors onto the horizontal shelf on the cup, from whence it is again projected out through the gas space, this process being repeated as often as there are deflectors and shelves in the machine. A tray (6) is placed above the inverted cup, this tray carrying drying material if it should be desired to dry the gas in the machine. The gas, after being subjected to the violent agitation in the central tube, and after passing through several sheets of water in its final upward passage, passes through the drying material into the gas space (7) and finally leaves the device at (8).

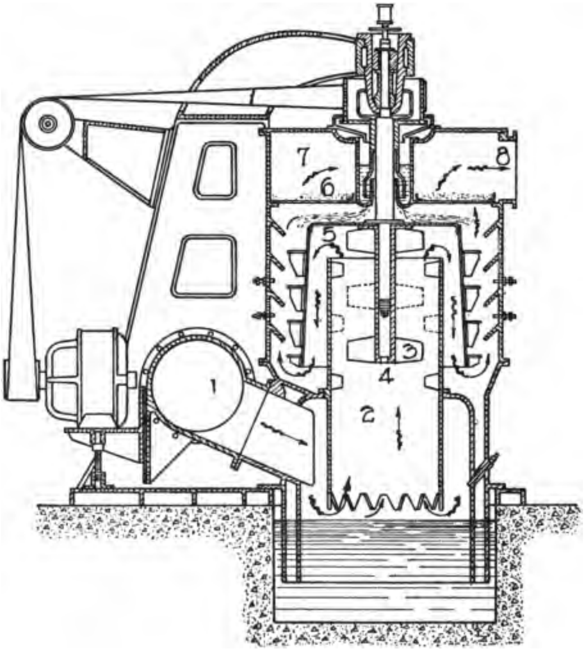


FIGURE 18. — Reco Centrifugal Washer

This washer is designed to accomplish the results produced in some of the other spraying centrifugals, but it seems as if its very structural nature must tend to remove any such successful issue. The washing water is thrown out into space in a thin stream from the horizontal shelves attached to the inverted cup, while the water spray in some of the others has a depth of from twelve to eighteen inches in each section, dependent upon the size of the washer; again, if these shelves are not absolutely horizontal more water will be thrown off at one point than at another, with the result that the gas will follow the line of least resistance and pass through the space but slightly filled with water, and thus escape the desired cleaning. Besides this, the water cannot be broken up into a spray by these horizontal shelves, but must leave them in a sheet, which also tends to decrease the efficiency.

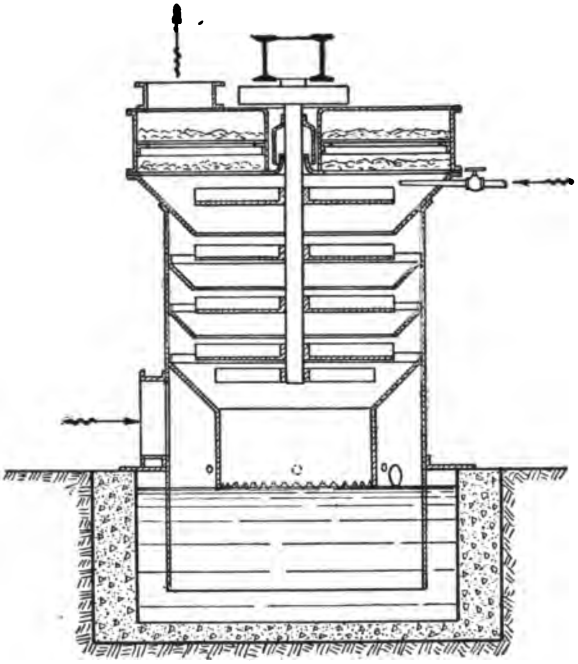


FIGURE 19. — Ernst Gas Cleaner

The Ernst Centrifugal Washer. — This washer, shown in Figure 19, embodies some of the principles applying to the Reco washer, but its construction is not quite so elaborate;

and the same disadvantages as in the Reco are also inherent here, in that the water is thrown off the revolving plates in a sheet, with a possible short circuit of gas due to the plates not being perfectly level over their entire area.

The Acme Washer. — The Acme washer, Figure 20, consists of several washing chambers of rectangular form, mounted one above the other, each chamber containing a wheel casing within which is mounted a vaned wheel of a design to give little resistance in the water. The gas enters the bottom chamber of the washer at (*A*), passes up beside the wheel casing at (*B*), and then at right angles to the passage (*C*) leading up to the next chamber; these changes in direction occurring as often as there are chambers in the washer; finally leaving through the separator chamber at (*D*), this latter chamber being supplied with a number of screens

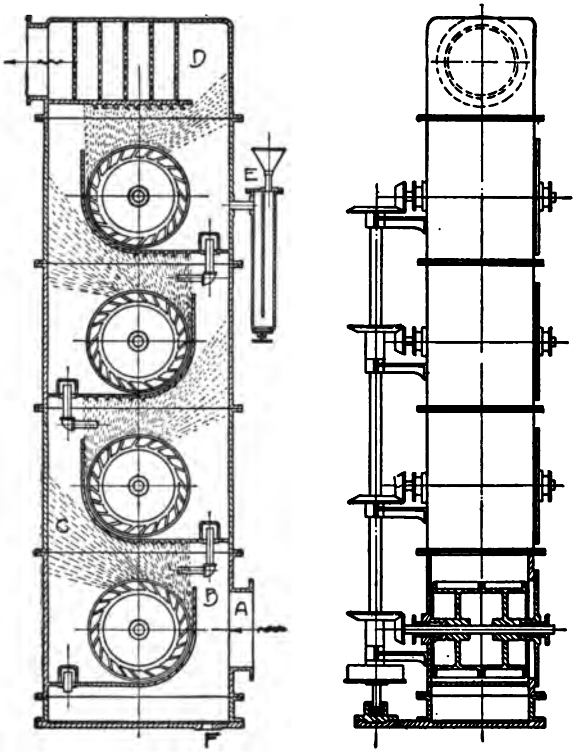


Figure 20. — Acme-Turbo-Washer

to throw back the entrained water. Water is admitted into the washer at (*E*) and fills the wheel chamber to the height of the overflow, after which it flows into the next chamber and so on down to the water outlet (*F*) at the bottom. The projector wheels revolve in opposite directions, and they fill the entire gas space with a very fine mist of water; the bottom of each wheel casing is provided with a series of serrated ribs for the purpose of dividing the water over the entire wheel area when the projected water falls back into the casing. One side of each washing chamber is provided with a large removable plate carrying the horizontal wheel shaft in a ball-bearing and stuffing box; this plate can be removed and the projector wheels taken out of any chamber in a very few minutes, after which the plate can be replaced and the washer operated without having disturbed any other chamber.

CHAPTER IV

THIRD STAGE. FINAL CLEANING

The Feld Centrifugal Washer is also used for the final cleaning of the gases for gas engine consumption, but in this instance only four washing chambers are provided, as the condensation of the water vapor is accomplished in the seven section primary washer.

The best known of the final cleaners, and the one which has heretofore been most widely adopted in both Europe and America is the

Theisen Washer. — The name of Theisen is familiar to all who have had any connection with the cleaning of blast-furnace gas, as the Theisen machines were the first ones produced which permitted of practical cleansing of these large gas volumes in a device which occupied but little space compared with their efficiency, this efficiency soon leading to their universal adoption, and they have kept their pre-eminent position for years.

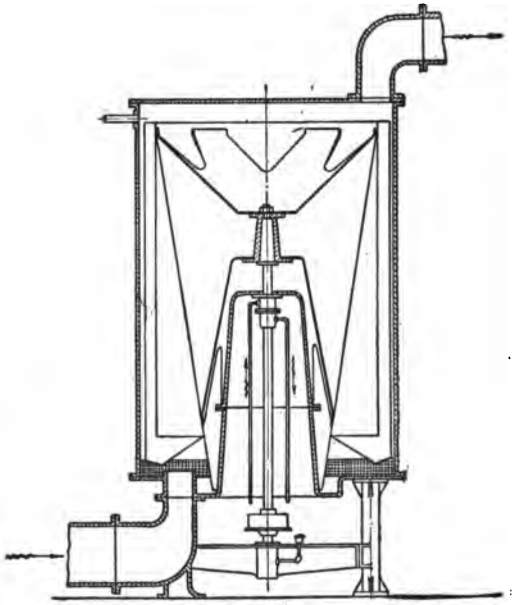


FIGURE 21. — Theisen Vertical Washer

The first Theisen washers were of the vertical, centrifugal type, shown in Figure 21, and they were placed in operation in 1898, but this machine soon proved unsuccessful, and it was soon followed by a machine of horizontal design; the power requirements of this device are excessive, and in consequence other washers were devised within the last few years which require but a small fraction of the Theisen power, notably the Feld, with the result that this latter device is finding more and more favor every day among European smelters.

The Theisen washer does not lend itself very well for primary cleaning, as the large amount of dust contained in the gas soon clogs up the openings in the wire mesh, calling for periodic shut-downs for cleaning purposes. If the gas is very hot and dirty, a preliminary saturator is generally placed before the Theisen for the purpose of cooling the gas and for removing the heavier dust particles, the static towers explained above taking the place of the Theisen saturator as a rule. The volume of the gas entering the washer is reduced by these towers, and less water, with a consequent reduction in power, is therefore required in the washer. The amount of water used varies with the quality of the gas, but this may reach as much as ten gallons per 1000 cubic feet of gas cleaned; a vapor separator is usually fitted to the outlet of the washer for the purpose of drying the gas.

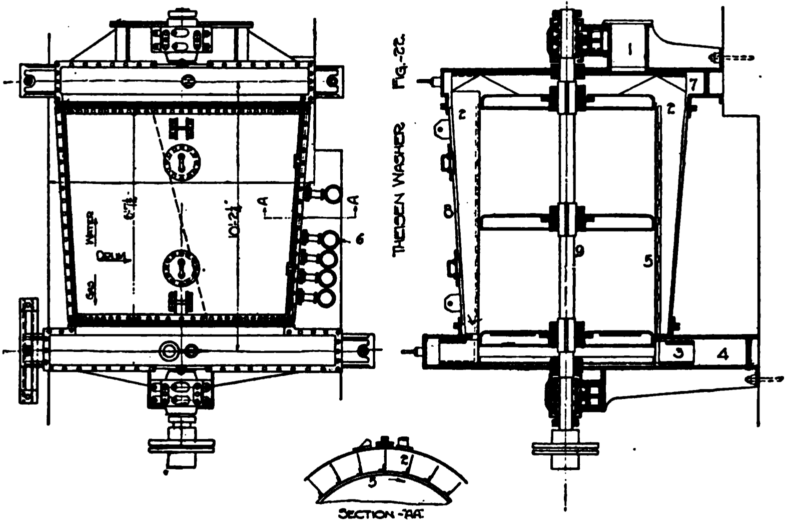


FIGURE 22. — Theisen Horizontal Washer

The Theisen washer, shown in Figure 22, consists of a horizontal shaft (9) to which is attached a steel drum (5) supported by means of spiders and diaphragms. A number of plates (2), standing at an angle to the horizontal shaft, and forming helical vanes, are attached to the outer surface of the drum, the angle of inclination being shown by the dotted line passing through the center line of the plan view, the vanes being wider at the gas inlet side than they are at the outlet side. A fan wheel (3) is attached to the extreme end of the shaft at the outlet end.

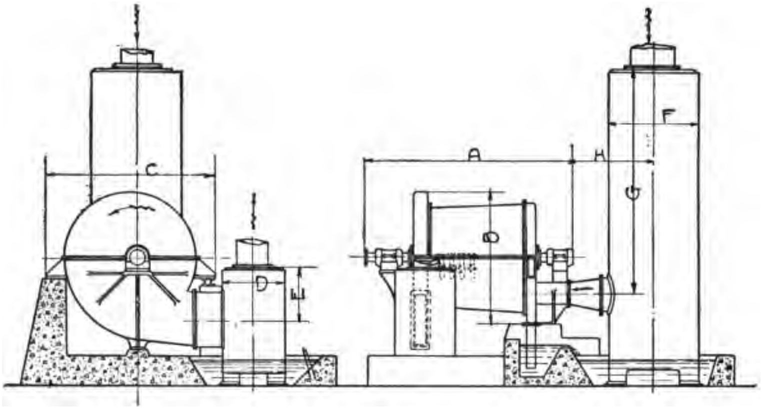


Figure 23.— General Arrangement of Theisen Washer with Separator and Preliminary Saturator

Gas enters the washer at (1) and is sucked through the washer by the exhauster fan (3) and discharged at (4), the helical vanes (2) acting to resist the passage of the gas and to hold it back, the result being that the gas is compelled to hug the casing (8) beyond the tips of the vanes, the forward sides of the vanes themselves compelling the gas to follow a helical path of several turns during its passage through the washer.

Water is admitted at (6), and flows in a direction opposite to that of the gas, leaving at (7). As is the case with the gas, the water is also forced tightly against the casing and made to take a helical course, but in a direction opposite to that of the gas, thus ensuring intimate contact between gas and water. The inside of the casing (8) is covered with a coarsely woven wire screen, the wires being set at an angle to the shaft, so as to assist the helical flow of gas and water, the rough surface of the screen greatly aiding in mixing gas and water. This washer is most efficient at a temperature of from 250° to 300° F.

The method of setting these washers, saturators and separators is shown in Figure 23, the saturator being required only when the gas is hot and extremely dirty, but the water separator should always be applied. Table III shows the capacity and dimensions of the Theisen washer, while Table IV gives the dimensions of the corresponding saturators and separators.

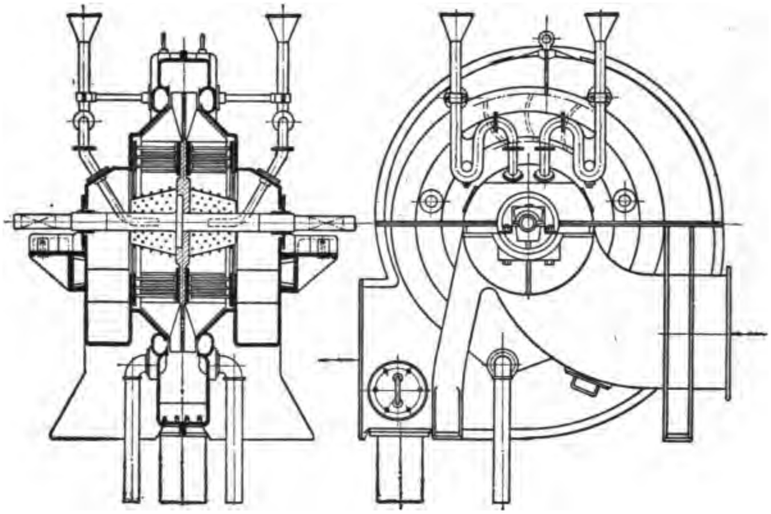


FIGURE 24.—Theisen Joint-Current Disintegrator

In order to meet the requirements of modern blast-furnace practice, and in order to reduce the cost of operation, Theisen has lately brought out a new device known as a "Disintegrator," which requires less power to accomplish the same result than was the case with the old horizontal machine just described.

This new machine is built in two styles, one being of a joint-current design, and the other on a counter-current principle. The joint current machine is shown in Figure 24, and it is so designed that both gas and water travel from the inside to the outside of the machine, the outer casing of the apparatus being built similar to that of a fan. The gas is divided and caused to enter the device on both sides at the center, leaving the middle of the machine at the bottom. The outside of the casing is provided at the inlets with ring bearings carrying the shaft, a cast steel disc being mounted on the middle of the shaft, a cast steel ring bearing cylinders of angle iron being arranged on both sides of this disc, similar rings carrying stationary cylinders being attached to the inner walls of the casing, these rotating and stationary cylinders being arranged concentrically one inside the other.

TABLE III

Capacity and Dimensions of Theisen Washers

No.	Max. Capacity Hot gas in cu. ft. per min.	Revolutions per min.	B. H. P. required	A	B	C	Water in gal per min.
1	1,170	700	20- 25	9′ 10″	5′ 6″	6′ 6″	8
2	3,400	600	34- 45	11′ 3″	7′ 5″	9′ 0″	22
3	5,300	450	50- 60	12′ 7″	8′ 8″	10′ 10″	36
3 A	7,400	450	60- 70	13′ 1″	8′ 10″	11′ 6″	46
4	10,600	380	80-100	15′ 5″	10′ 6″	12′ 9″	71
4 A	14,100	370	110-125	16′ 5″	11′ 2″	13′ 2″	93
5	17,650	300	140-155	17′ 8″	14′ 1″	15′ 9″	112

TABLE IV

Dimensions of Corresponding Saturators and Separators

Number	F	G	H	D	E
Saturator				Separator	
1	4′ 0″	8′ 3″	3′ 6″	3′ 0″	2′ 0″
2	5′ 0″	11′ 6″	3′ 9″	3′ 3″	2′ 7″
3	6′ 0″	14′ 9″	4′ 2″	4′ 0″	3′ 0″
3 A	6′ 0″	14′ 9″	4′ 2″	4′ 0″	3′ 3″
4	6′ 6″	16′ 5″	4′ 6″	4′ 3″	4′ 3″
4 A	7′ 3″	18′ 0″	5′ 0″	4′ 6″	5′ 1″
5	7′ 10″	19′ 8″	5′ 6″	5′ 0″	5′ 11″

The wash waster is admitted into the machine by means of syphons, being discharged upon a distributing cone carried on the shaft, this cone being perforated besides carrying spray plates on the outside, thus causing the water to be finely divided and made to strike upon the first rotating cylinders, these cylinders, both rotating and stationary, being constructed of angles or round steel bars. This action causes a mixturc of gas and water, this mixture being projected against the recoil surfaces of the stationary cylinder, thus breaking up the water into a very fine mist and further mixing it with the gas, causing a thorough wetting of the dust burden in the gas. This action is repeated as many times as there are rotating and stationary disintegrating cylinders in the machine, and in this manner the dust particles are taken up and retained in the water.

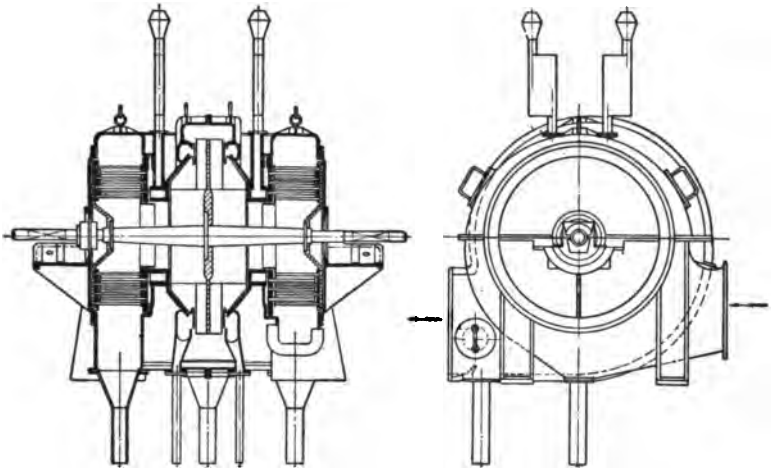


FIGURE 25.—Theisen Counter-Current Disintegrator

The mixture of gas and water is drawn through the machine by the action of the fan blades mounted on the outer part of the disc. These blades are so constructed that the inner portions of the blades project the gas-water mixture against the washing surface, the latter being concentric to the fan blades. The water vapor carrying the dust burden separated from the gas moves to the outside as a fluid sheet, while the gas is repeatedly hurled against this sheet of water in a manner similar to that described in the old design of Theisen washer.

As the water moves outwards it is gathered at the edge of the surface in a water groove which leads it away from the gas space, thus preventing it from coming into contact with the fan blades. It is claimed that this latter feature is the reason for the small power requirement as well as for the higher pressure produced.

The fan blades are shaped radially on their outer surface, thus making them pressure blades, this construction closing the blades sideways; they thus force the cleaned gas against the fan casing from whence it passes into the gas main under the pressure produced by the machine.

In the counter-current machine, shown in Figure 25, the gas flow is opposite to that of the water, the gas entering at the bottom of the machine where it meets the first water spray thrown out by the disintegrator rods. The same agitation and mixing of gas and water takes place as explained above, but owing to the counter-current principle this machine is preferred for use on hot and very dirty gas.

The results obtained with the first Theisen disintegrator, built for the collieries at Gelsenkirchen in 1909, are given in Table V.[1]

TABLE V

Theisen Disintegrator Results at Gelsenkirchen

Gas Volume cubic feet per hour	Gas Pressure in inches of water		Dust Content in grains per 100 cubic feet		Water Used in gallons per M. cubic feet	H.P. per 1000 cubic feet	Revolutions per minute
	Inlet	Outlet	Inlet	Ontlet			
360,000	1.58	3.94	175	1.35	8.5	0.1105	515

A Theisen Disintegrator with water separator has been in continuous operation at the Differdinger furnaces since the latter part of 1912; this machine was installed as a primary cleaner with a capacity of 1,412,000 cubic feet of gas per hour, and was guaranteed to clean the gas of dust from a content of 175 grains per 100 cubic feet to from 13 to 22 grains per 100 cubic feet. It was soon found, however, that the raw gas only had a dust content of from 39 to 66 grains per 100 cubic feet, and the final results were therefore better than had been anticipated. In consequence of the results secured with this machine, these furnaces are now being supplied with disintegrators having a capacity of 1,765,000 cubic feet of gas per hour, giving a pressure differential of about 14 inches of water, thus displacing two exhausters now in use.

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[1] See "Stahl und Eisen," 1913, Page 2099.

The results obtained at Differdinger are given in Table VI.[1]

Two Theisen Disintegrators are being operated at the Rombach Collieries; these machines were built to treat 1,059,000 cubic feet of gas per hour and were guaranteed to reduce the dust content of the gas from 0.044 grain to 0.0087 grain per cubic foot with a water consumption of not more than 5 gallons per 1000 cubic feet. The results of tests made at Rombach are given in Table VII.[2]

Two Theisen Disintegrators, one having a capacity to treat 1,412,000 cubic feet, and the other 1,588,500 cubic feet per hour have been in operation at the Hasper furnaces for some time, and it is stated that these machines clean the gas of dust from 8.75 grains down to 0.8 grain per 100 cubic feet, requiring 150 horse power to operate with a water consumption of 3.25 gallons per 1000 cubic feet.

It is stated that this disintegrator will cool and clean the gas without any previous treatment; this is possible, providing sufficient water for this purpose is introduced into the machine, as the cooling of the gas is entirely a thermal question. Upon examination of the tests given for the machines at Differdinger and at Rombach it will be seen that the inlet temperature of gas and of water closely approximate each other, and as the inlet temperature of the gas is as low as 84° F. in one case it must be assumed that the gas underwent a previous cooling of some sort. The more water injected into the machine, the more power will be consumed, and as the cost of power is far in excess of that of water, the former should be kept at a minimum. The disintegrating effect of the drums is such that very fine water will probably be vaporized if the gas should be of high temperature, and additional water would then have to be used to again precipitate this vapor.

The Edward Theisen Company, Munich, Germany, state that at a cleaning plant in Luxemburg[3] these disintegrators, treating the gas for hot-blast stoves and boiler consumption, with a capacity of 1,750,000 cubic feet of gas per hour, operat-

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[1] See "Stahl und Eisen," 1913, Page 2100.

[2] See "Stahl und Eisen," 1913, Page 2101.

[3] See Bulletin of American Institute of Mining Engineers, Dec., 1913.

TABLE VI

Theisen Disintegrator Results at Differdinger

Gas volume in cu. ft. per hr. at 122° F.	Gas pressure in inches of water		Pressure increase	Dust content grains per 100 cu. ft.		Gas temperature degrees F.		Water temperature degrees F.		Water used gal. per 1000 cu. ft.	H. P. per 1000 cu. ft.	Rev. per min.
	Ahead of washer	After washer		Ahead of washer	After washer	Ahead of washer	After washer	Ahead of washer	After washer			
1,564,743	− 2.78	+ 5.13	7.91	44.3	0.872	104	105	86	103	4.86	0.1572	668
1,671,561	− 3.55	+ 5.90	9.45	43.6	0.524	91	92	84	92	3.95	0.1540	658
1,712,580	− 3.35	+ 6.02	9.37	41.2	0.786	92	95	85	93	3.91	0.1480	649
1,645,368	− 3.35	+ 6.23	9.58	38.4	0.350	91	92	84	92	3.05	0.1417	677

TABLE VII

Theisen Disintegrator Results at Rombach

1,067,896	− 1.18	+ 7.74	8.92	9.6	0.61	84	88	81	87	3.90	0.116	600
1,070,000	− 0.90	+ 5.40	6.30	15.3	0.70	87	88	80	88	4.95	0.127	604
1,519,665	− 2.16	+ 5.14	7.30	16.1	0.83	. .	. .	. .	. .	2.74	0.082	605

ing at 627 revolutions per minute, and requiring 230 gallons of water and 12 horse power per 100,000 cubic feet of gas, cleaned the gas of dust from 0.5 grain to 0.01 grain per cubic foot, the gas having a pressure of 2.7 inches of water ahead of the disintegrator, and 5.6 inches after having left it. Under these conditions, and without considering amortization and interest, as the cost of the plant is not given, the operating costs per year would be:

Power, 12 × 17.50 × 24 × 0.746 × 360 × 1¢ per K. W. H.	$13,535.00
Wages, 2 men, one man per shift	1,095.00
Maintenance, lighting, oil, etc.	600.00
Water, 35 million gallons, @ $10.00	350.00
Total operating cost per year	$15,580.00

The gas to be cleaned per year amounts to 15,120,000,000 cubic feet, making the cost of cleaning 100,000 cubic feet of gas for hot-blast stoves and boilers,

$$\frac{\$15580.00}{151200} = 10.30 \text{ cents.}$$

At the same plant the Theisen disintegrators, operating at 658 revolutions per minute, cleaned the gas for engine consumption from a dust content of 0.4 grain per cubic foot down to 0.005 grain per cubic foot, requiring 16 horse power and 415 gallons of water per 100,000 cubic feet, the pressure of the gas ahead of the disintegrator being 3.5 inches, and behind the disintegrator 6 inches of water.

Assuming the same quantity of gas cleaned per hour as in the above case, or 1,750,000 cubic feet, and not considering amortization and interest, as the cost of the plant is not given, the cost of operation per year would be

Power, 16 × 17.5 × 24 × 0.746 × 360, @ 1¢ per K. W. H.	$18,047.00
Wages, 2 men, one man per shift	1,095.00
Maintenance, lighting, oil, etc.	600.00
Water, 63 million gallons, @ $10.00	630.00
Total operating cost per year	$20,372.00

This would make the cost of cleaning 100,000 cubic feet of gas for engine consumption,

$$\frac{\$20372.00}{151200} = 13.48 \text{ cents.}$$

The Reading Centrifugal Washer.— This device is housed in a split-casing, Figure 26, and consists of either a one or a two stage rotor mounted upon a horizontal shaft, the rotor comprising a pair of spaced discs provided with a set of radially disposed blades on both sides of each disc. The casing is divided into two communicating compartments, each of which is made to enclose one of the bladed discs, thus forming two independent stages for the extraction of dust. A set of nozzles is provided for each stage and these direct the water spray toward the rotor blades.

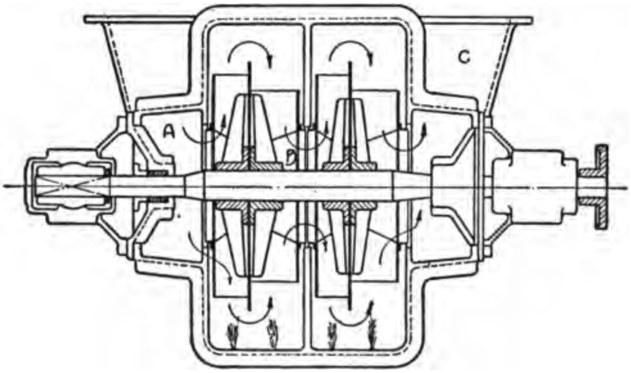


FIGURE 26. — Reading Centrifugal Washer

The gas enters the casing from the rear and passes centrally into the first set of disc blades at *A*, where the rotor imparts an intense whirling motion to the gas. The rotor is balanced, and runs at from 1700 to 1800 revolutions per minute. The gas is forcibly thrown against the concentric casing wall and is thus mixed with the wash water, after which it passes to the opposite side of the first rotor disc and is made to flow against the second set of blades.

Thereafter the gas enters the second stage at *B* in a manner identical to that described for the first stage, and meets a fresh supply of water, after which the gas is discharged into the outlet pipe *C* at the rear of the casing. The waste water with its dust contents is carried to the bottom of the casing, where each stage discharges through separate water sealed legs.

It is stated that 40 horse power is required to operate this device per 1000 cubic feet of gas per minute, and that the water required amounts to from 40 to 50 gallons per 1000 cubic feet of gas cleaned.

These scrubbers are built in two sizes, one having a rated capacity of 750 cubic feet per minute, and the other of 1500 cubic feet per minute.

The Schwarz-Bayer Disintegrator. — The Schwarz-Bayer system claims to do away with cooling or spraying towers, the gas-cleaning apparatus consisting of the disintegrator in connection with a hood shaped saturating chamber, behind which is placed a fan and then a water separator. If both primary and final cleaning is to be accomplished two sets of apparatus will be required, the second set being used for the final stage.

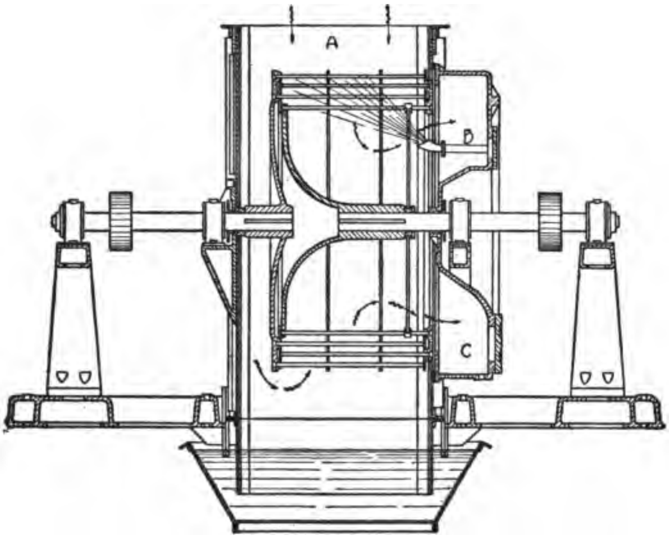
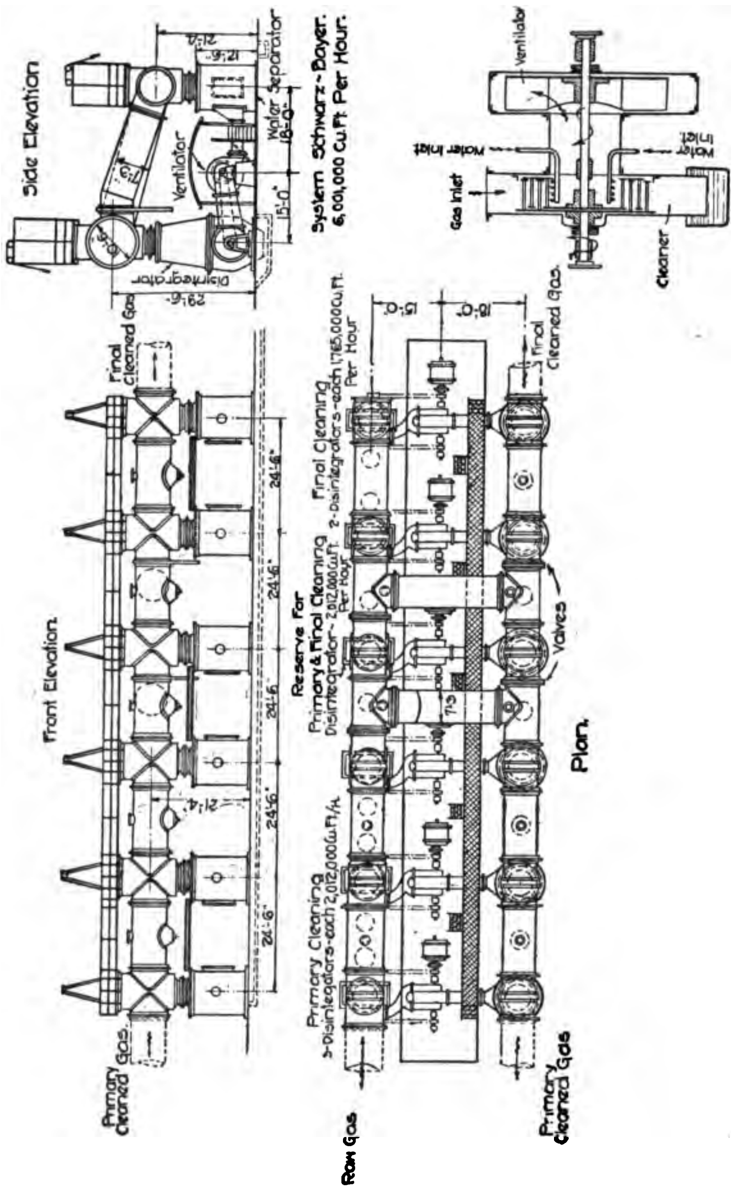


FIGURE 27. — Schwarz-Bayer Disintegrator

The Schwarz-Bayer disintegrator, or washer, is shown in Figure 27, and consists of two steel discs provided with two sets of projecting steel pins or rods, similar to the Theisen construction, the discs being set side by side and revolving in opposite directions. The projecting rods of one revolving disc interlace with the pins or rods of the other revolving disc and, due to the effect of rotation and dripping, produce a fine water spray or mist, thus causing a thorough mixture of water and gas, as the latter is compelled to travel in and



Cleaner & Ventilator

FIGURES 28 and 29. — Arrangement of Schwarz-Bayer Cleaning Plant out between the projecting rods before it can leave the device.

The gases from the blast-furnaces, after passing through a dry dust catcher, pass directly into the disintegrator without passing through any intermediate cooling or spraying towers. The gas enters through the top of the hood at *A*, and then travels toward the center of the machine, while the water is injected at *B*. The hood assumes some of the functions of a pre-cleaner and cooler, as a portion of the spray from the disintegrator is projected into the hood, where it comes in contact with the hot gas and is consequently evaporated, thus absorbing some of the heat from the gas. During rotation of the discs the water is projected toward the periphery of the apparatus, where it is broken up into a fine spray, the gas mixing with this water and being thus cooled, the dust content being precipitated, and the gas then finally leaving the device at *C*.

The machine is operated on the counter-current principle, and in consequence the gas encounters cleaner and colder water during its passage through the scrubber; this aids in cleaning the gas, and the temperature of the gas is thus reduced more nearly to the temperature of the entering cooling water. Each disc is driven direct by an individual motor, and the required speed is determined by the required degree of gas cleanliness.

The original design of the Schwarz-Bayer disintegrator combined the cleaner and the exhauster on a common shaft, as shown in Figure 28, but this method of construction soon produced many operating difficulties, and it therefore became necessary to separate the machine into three parts, disintegrator, exhauster, and water separator and to arrange them independently of each other, as shown in Figure 29,[1] which depicts a complete cleaning plant having a capacity to clean 6,001,000 cubic feet of gas for use under hot-blast stoves and boilers, and 3,530,000 cubic feet for gas engine consumption.

By referring to Figure 29 it will be seen that the gases from the furnace and dry dust catcher immediately enter the disintegrator, from whence they are drawn by the exhauster and forced through the water separator where the gas is divided, one portion passing to the hot-blast stoves and boilers, while the other portion is led to a second disintegrator which cleans it to a degree suitable for engine consumption.

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[1] See "Stahl und Eisen," 1913, Page 642.

These machines are said to consume from 1.5 to 2 inches of water pressure in the primary cleaners, while the final cleaners throw a back pressure of 8 inches of water, thus necessitating the use of a fan or exhauster to carry, or force the gas forward. It is stated that the builders figure on a consumption of about 0.08 to 0.09 horse power per 1000 cubic feet of gas in the primary cleaners, and about 0.115 horse power for the final cleaners, the water used ranging from 3.75 to 7.5 gallons per 1000 cubic feet.

At Donawitz, Austria, a primary cleaning plant having a capacity of 1,588,500 cubic feet of gas per hour has been in operation for some time, and the published data covering this installation is as follows:

Inlet temperature of gas 130° to 200° C. = 266° to 392° F.
Outlet temperature of gas 39° to 42° C. = 102° to 108° F.
Dust content of raw gas 1.8 to 2 g/cbm. = 0.785 to 0.87 gr. per cu. ft.
Dust content of cleaned gas 0.07 to 0.12 g/cbm. = 0.031 to 0.053 gr. per cu. ft.
Water used, 0.56 to 0.78 l/cbm. = 4 to 6 gals. per 1000 cu. ft.
Power used, 0.079 to 0.0814 H. P. per 1000 cu. ft.

This plant is for primary cleaning only, and if the gas is to be cleaned for engine consumption further treatment, requiring additional apparatus, will be required. It will therefore be assumed that about one-half, or 75,000 cubic feet per hour are to receive final treatment, the cost of cleaning 100,000 cubic feet, less amortization and interest, then being given by

Power, 1,477,440 K. W. H. in 360 days, @ 1¢ per K. W. H.	$14,774.00
Wages, 2 men, one man per shift	1,095.00
Maintenance, lighting, oil, etc.	600.00
Water, 75 million gallons, @ $10.00	750.00
Total operating cost per year	$17,219.00

and the cost of cleaning 100,000 cubic feet of gas will be

$$\frac{\$17219.00}{137246} = 12.55 \text{ cents.}$$

The small amount of water used in this plant, and the small amount claimed by the builders, can only be explained by the fact that the heat of the gas must necessarily vaporize quite a quantity of the water, thus adding to the burden of water vapor in the gas instead of diminishing it, making the disintegrator a cleaner only, and not a cooler. The proper cooling of the gas demands not only that its temperature be reduced to about 80° F., but also that its water vapor be condensed, and the design of all disintegrators such as this necessitates a higher power consumption with increased water injection, as the power required can be computed as in direct proportion to the amount of water used and the square of the periphery speed of the machine; besides this, it can readily be seen that increased water injection requires additional power due to the continuous acceleration of the water as it approaches the periphery, which will necessarily induce quite a considerable loss of thrust by throwing out and pulverizing the nearly inelastic water, due to the disintegrator rods revolving in opposite directions.

It may therefore be that the amount of water used is kept at a minimum, or sufficient to clean the gas, in order to reduce the power requirements, and that in order to properly remove the water vapor condensation should be applied after the gas is cleaned. Conditions such as applied during this test cannot always be realized in steel plants; the degree of dust in the raw gas was low, the temperature of the cleaning water was only 50° F. at the inlet and other conditions could not have been normal ones, or such as could be applied in general.

The following calculation will give the amount of cooling and cleaning water required under normal conditions, and this amount greatly exceeds the amount claimed for this test run.

Taking the average figures given for the plant at Donawitz, it will be necessary to reduce the temperature of the gas from 165° to 40° C., and the dew point of the gas for water will be assumed to be at 50° C., allowing the temperature of the cooling water to increase from 10° C. to 40° C., or to 10 degrees below the dew point; it is stated that in this test run the injection water reached a temperature of 50° C., a condition which can only occur when water is vaporized, otherwise the temperature must remain below this point if the water is to be precipitated and not absorbed in machines of this character.

By referring to Table I, it will be seen that the total heat content of a water-saturated gas at 50° C. amounts to 85.13 calories per cubic meter, and that the specific heat of the gas is 0.383 calorie per cubic meter.

At 165° C. the heat value will therefore be $85.13 + 0.383 (165 - 50) = 129.18$ calories, referred to water contents, and the amount of cooling water required to reduce the temperature of the gas from 165° to 40° C. is proportional to this total heat content. At 40° C. the total heat in the cooled gas amounts to 51.69 calories, and $129.18 - 51.69 = 77.49$ calories must therefore be absorbed by the water.

As the temperature of the injection water is 10° C., and as it is to be heated to 40° C., one liter of water will absorb $40 - 10 = 30$ calories, and for the absorption of 77.49 calories there will be required $\frac{77.49}{30} = 2.58$ liters of water per cubic meter of gas, equivalent to 18.5 gallons per 1000 cubic feet, requiring in the above example of cost 254 million gallons for primary cleaning and efficient cooling and, allowing the given amount for final cleaning, or 4 million gallons, the cost of cleaning 100,000 cubic feet of gas will be 13.89 cents, and that with a final gas temperature of 40° C. instead of 26° C. (79° F.) usual in America.

To reduce the gas to this latter temperature, and to place all of the systems cited on the same basis, would require about 25 gallons of water per 1000 cubic feet of gas, giving a total of 347 million gallons for complete cooling and cleaning, and making the cost of cleaning 100,000 cubic feet of gas equal 14.52 cents.

This same condition applies to all disintegrators where such small water consumption is claimed, and if the proper amount of water is used to both cool and clean the gas, and to condense the water vapor, the power required will increase proportionally.

The Stolte Rotary Washer. — The Stolte apparatus consists of a casing carrying a horizontal shaft, a drum provided with vanes being mounted on the shaft and revolving with it, as shown in Figure 30.

The gas enters the apparatus from both sides at (*E*), meeting a flat stream of water at (*t*) as soon as it enters the casing, mixing with the water at this point and being then picked up by the vanes marked (*h*), which pulverize both gas and water and thus form an intimate mixture. Two outlets marked (*m*) are provided for drawing off heavy sediment thrown out by the vanes (*h*).

The gas and the water are both forced into the casing by the vanes on the drum (*d*) and thus produce an enclosing wall of water circulating upon the inside of the casing (*a*), the gas and water being thereby compelled to move from both sides towards and into the fan (*c*) located in the center of the apparatus; as the gas and water both circulate over the washing drums located at both sides of the pressure fan, the wash water extracts a further portion of dust from the gas under the action of pressure produced by the vanes (*h*).

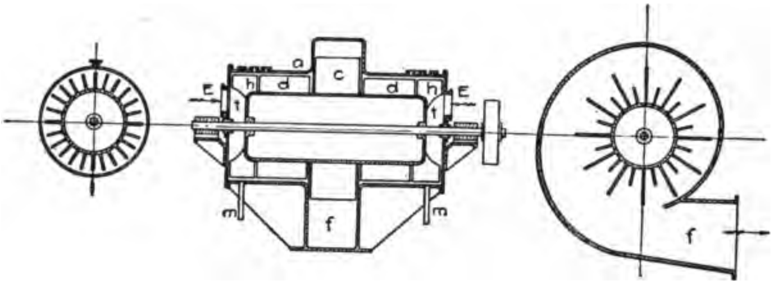

FIGURE 30. — Stolte Rotary Gas Washer

In this manner the water is caused to form an annular mantle or wall, concentrically surrounding the gas, the gas entering the fan from both sides and rebounding, thus causing the stream of gas to break through the closed annular wall of water. The water is again pulverized at this point and immediately mixed with the gas by the pressure wings of the fan (*c*); upon leaving the pressure wings the water is projected in the shape of jets in a radial direction against the walls of the spiral casing, while the gas passes tangentially to the outlet (*f*), or at right angles to the stream of water.

The same claims are advanced by the builders of this device as those given for the other disintegrators, and they are all in the same class, differing only in constructive features, but operating on practically the same principles, using the old fan type of cleaner as a model, and all operate at high speed.

The advantages claimed by the builders of this device are:

(1) A high degree of cleansing, the dust content being reduced to 0.0044 to 0.0088 grains per cubic foot.

(2) Lowest possible consumption of water, amounting to from 3 to 9 gallons per 1000 cubic feet.

(3) A high degree of cooling, thus eliminating spray towers or other cooling devices.

(4) Small power consumption, 0.12 to 0.18 B. H. P. per 1000 cubic feet of gas.

(5) High number of revolutions, thus decreasing the dimensions of the apparatus.

These machines have been placed in operation at the Burbacher Huette, Saarbrucken, Germany, Aplerbecke Huette, Dortmund, Germany, Soc. d'Athus-Grivéguée, France, and Soc. des Acieries de France, Isbergues.

It is also claimed that if the gas is to be used for engine purposes a final cleaning will not be necessary, as the one machine can be made, by somewhat changing the design, to accomplish both primary and final cleaning.

The Fowler and Medley Washer. — This device is pictured in Figure 31, and consists of a circular casing containing a revolving, vertical shaft, this shaft being provided with a number of fixed discs, the discs being made either of steel or cast-iron. The discs are separated from each other by means of a collar, or distance piece surrounding the shaft, this collar being a part of the disc. Motion is imparted to the shaft by means of a vertical spindle motor mounted directly upon the top end of the shaft.

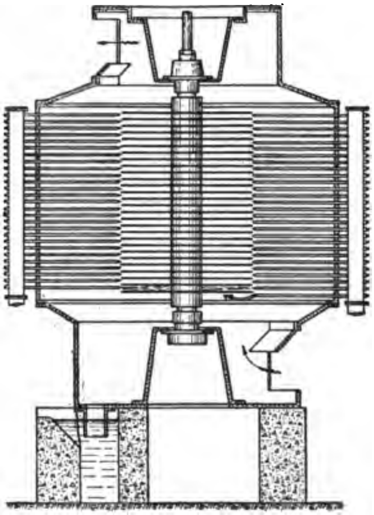

FIGURE 31. — Fowler and Medley Vertical Washer

Each disc is provided with fixed water sprays, placed opposite each other, and projecting between each pair of discs. These sprays have nozzles with an eighth-inch diameter opening, the water from the nozzles entering the space between the discs with sufficient pressure to forcibly strike the collar and, as the discs revolve, the water is reversed and thrown out against the top and bottom of the discs and from thence against the walls of the casing, thus creating a fine spray or mist in the space between the outer edge of the disc and the wall of the casing, the gas passing through this space. The gas enters the apparatus at the bottom, passes through the water spray, and leaves at the top.

In a statement prepared by the Fowler and Medley Company, of Liverpool, England,[1] the cleaning plant erected by them at Manchester is described as consisting of five cleaners, each having a capacity of 500,000 cubic feet of gas per hour, each cleaner requiring 11 K. W. for its operation, while the plant consumes 6000 gallons of water per minute for cooling the gas and cleaning it sufficiently for use under the hot-blast stoves and boilers.

This amount of water is far in excess of that used in any other system, and amounts to 144 gallons per 1000 cubic feet of gas.

If the gas is to be used for engine consumption another set of machines would be required, these final cleaners consuming about the same amount of power, but only 150 gallons of water per minute. Each cleaner throws a back pressure of about 3/8″ of water.

According to the above statement the five primary cleaners, treating 2,500,000 cubic feet of gas per hour, and say three final cleaners treating 1,250,000 cubic feet of gas per hour for gas engine consumption, would require a total of

21,600,000 × 144 = 3,110,400,000 gallons, plus
15,800,000 × 7.2 = 113,760,000 gallons, or

a total per year of 3,224,160,000 gallons of water, and the cost of cleaning 100,000 cubic feet of gas, less interest and amortization, would be given by

Power, 8 × 11 × 24 × 360 @ 1¢ per K. W. H.	$7,603.00
Wages, 2 men, one man per shift	1,095.00
Maintenance, lighting, oil, etc.	600.00
Water, 3224 million gallons, @ $10.00	32,240.00
Total operating cost per year	$41,538.00

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[1] See Bulletin of the Am. Institute of Mining Engineers, Dec., 1913.

making the cost of cleaning 100,000 cubic feet of gas

$$\frac{\$41538.00}{216000} = 19.23 \text{ cents.}$$

Fans are not required in this plant, as the gas pressure is sufficient to send the gas forward to the point of consumption.

Before leaving the subject of vertical centrifugal washers, it may be well to point out the differences existing in the sprays thrown by the various machines. In the Feld, or in the Standard washers the spray can be made of any required depth, but in the Reco, the Ernst, and the Fowler and Medley machines the depth of spray is very limited, and in order to approach the depth given by the two former washers, the latter ones would have to be provided with an innumerable amount of horizontal spray plates.

Quite another difference exists in the speed of the vertical centrifugals as compared with the disintegrators; the verticals seldom require more than from 100 to 125 revolutions per minute, while a speed of from 600 to 700 revolutions in the disintegrators is common; this greater speed leads to power consumption, and this power consumption is increased by the pulverizing effect of the disintegrator; besides this, the high speed of these latter machines permits of but a short period of contact between gas and water, which is a serious disadvantage.

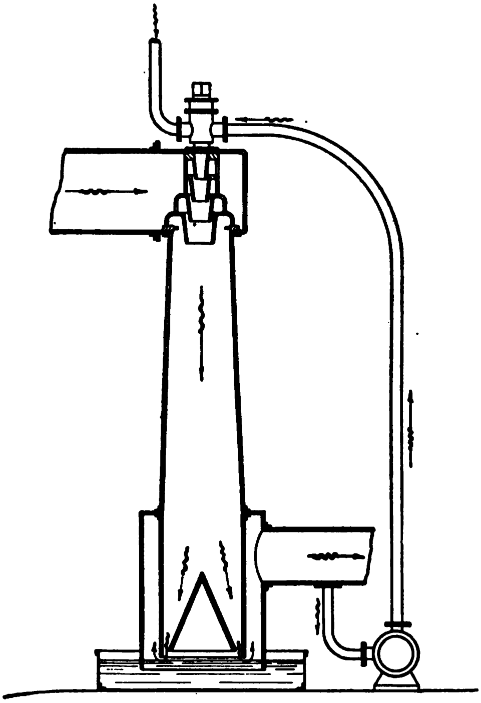

FIGURE 32.—Sepulchre Washer

Among the wet washers we find one more which is quite an ingenious arrangement; this is

The Sepulchre Washer. — The Sepulchre Washer is shown in Figure 32. This device is intended to be a final cleaner, and consists of a vertical, tower-shaped casing, the top being supplied with a fine spray of water produced by Korting injectors, the water being atomized under a pressure produced by means of compressed, cleaned blast-furnace gas. This arrangement produces quite an intimate contact between gas and water, and it is rated as a very efficient cleaner.

The bottom of this apparatus seals in water, and a deflector, consisting of a cone located in the base of the inner flue, the outer edge of the cone being but a short distance from the walls of the inner flue, compels the gas to pass through this space in order to reach the outlet. A portion of the cleaned gas is removed from the outlet pipe and forced by a compressor into the injector, where it meets and vaporizes the water.

CHAPTER V

THE "DRY" SYSTEM FOR FINAL CLEANING

The first "dry" system to meet with any degree of even partial success in steel blast-furnace practice, was that erected in an experimental manner at the Halberger Collieries, near Saarbruecken, Germany. This plant had a capacity of about 175,000 cubic feet per hour, the gas containing 2.6 grains of dust ahead of this cleaner, and 0.005 grain per cubic foot after passing through the filters, the whole scheme being an adaptation of the bag-house used by the copper smelter.

After passing through the filters of this experimental plant, water was injected into the gas shortly before it reached the gas engine, and its temperature was thus reduced to about 68° F. The first bags used had but a very short life, and it was necessary to find some material which would not be affected by the gas and its contents; the water vapor in the gas condensed on the bags and coated them with mud, thus rendering them ineffective. After these troubles had been located the operation was changed, in that the temperature of the gas was reduced to the dew point for water in an ordinary tower cooler, the tower being open at the bottom and dipping into a hydraulic seal, and as the dew point lay between 122° and 140° F., the gas was rapidly cooled to this temperature, and at which temperature the gas no longer had a bad effect upon the material of which the bags were made. In order, however, to prevent any caking on the bags the gas was heated, after its water had been precipitated, by means of a steam coil located in the cooler outlet. The gas in its superheated but dry condition then passed into the filter bags where the dust was removed. These experiments led to the development of the

Halberger-Beth System. — This system is depicted in Figure 33, and consists of a primary cooler, reheater, filtering compartment, fan, and final cooler. The gas from the blast-furnace down-comer is first led into a dry dust catcher of the usual design, after which it enters the primary cooler (*B*) at (*A*), where the temperature of the gas is reduced to the dew point required for the precipitation of its water contents. This primary cooler is usually so constructed that the gas can be cooled by surface radiation, or by direct contact with a water spray, the method used depending upon the gas temperature; the bottom of the cooler is open and is sealed in a water pit, the inlet (*A*) being so located that the entering gas impinges upon the surface of the water seal, while the outlet from the cooler is provided with a water sealed valve for the purpose of closing off the subsequent apparatus for repairs or cleaning.

The cooled gas next enters the reheater (*C*) where it is heated to a temperature of about 175° F. by means of steam coils, the bottom of this heater as well as the bottom of the neighboring filter compartment being provided with a screw conveyor (*D*) for carrying the precipitated dust into the dust catcher (*G*), from whence it is removed by the usual means.

After passing through the heater, the gas is conducted into the conduits located beneath the filtering compartments, where it ascends and passes through the filter bags, depositing the dust upon the inner surfaces of the bags. The bags are suspended from a rack in a series of double compartments, each compartment being supplied with from twelve to twenty bags, arranged in rows of four bags each. The bags are usually nine inches in diameter and ten feet long, equipped with rings spaced about eighteen inches apart for the purpose of preventing an entire collapse of the bags while they are being cleaned.

The lower ends of the bags are fastened to rings, or thimbles around the openings in the top head of the gas conduits, the bottom being thus held open for the entrance of the gas, while the top of the bag is closed by means of an iron plate, this plate being attached to the shaking mechanism automatically operated from the outside of the compartment, the bags being thus shaken about every five minutes for a period of from fifteen to twenty seconds. As stated above, these compartments are arranged in pairs, the one compartment receiving gas while the bags in the neighboring one are being shaken, the gas to the latter being shut off during this operation.

The gas is drawn through the bags under a slight pressure by means of the fan (*F*), or if the gas should have sufficient pressure of itself, the fan can be dispensed with; when this pressure is removed from the compartment, the bags are subjected to a partial collapse which, together with the vigorous shaking, causes the dust to fall into the conveyor hopper below.

The operation of this system requires first, that the gas temperature be reduced to the dew point for the precipitation of its water vapor; and secondly, that the temperature be then increased to about 175° F. so that the dust will be sufficiently dry to prevent caking the bags, but this temperature should not be exceeded, as otherwise there is great danger of scorching the bags and thus reducing their efficiency. After leaving the filtering compartments the gas will be found cleaned to a degree which will permit of its use in gas engines, but it is first passed through a final cooler (*H*) in order to properly reduce its temperature and thus its volume.

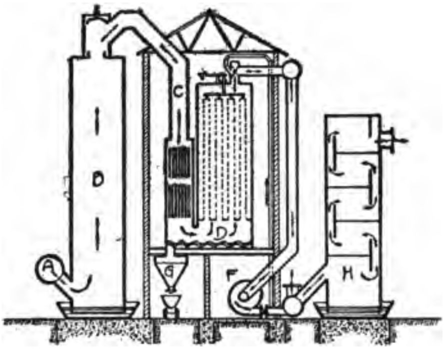

FIGURE 33.—Halberger-Beth Gas Cleaning System

In a statement issued by the Dingler Machine Shop Company, of Zweibruecken-Falz, Germany,[1] the guaranteed operating cost of cleaning 100,000 cubic feet of gas by the Halberger-Beth "dry" system, is given at from 10.7 cents to 14.3 cents, under German conditions, the higher figure being only applied when the installation, due to unfavorable local conditions, is extremely expensive. This Company states that only one operator with one assistant is required to operate the largest plant, and that they figure the average life of the bags to be six months, although these bags have been known to be in service for a period of eighteen months.

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[1] See Bulletin of the Am. Institute of Mining Engineers, Dec., 1913.

In the three statements given below for cost of installation and operation of plants, the factors have been made to conform to American costs, except in the price of apparatus, which has been maintained as given; this Company figures power at a little more than a half cent per horse power per hour, while in the appended statements power has been taken at one cent per K. W. H.

Plant No. 1. — Capacity: 2,330,000 cubic feet per hour, gas measured at 0° C. and 760 mm. pressure.

COST OF INSTALLATION

Apparatus, including reserve parts	$44,000.00
Large sheet steel work	10,000.00
Steel structure for building, 70 tons at $65.00	4,550.00
Foundations, masonry, roofing	700.00
Motors and motor equipment	3,000.00
Dust conveyor, etc.	500.00
Total cost of installation	$62,750.00

COST OF OPERATION

Amortization (10 %) and interest (5 %) on $62,750.00	$9,413.00
Power, 200 H. P. × 360 days × 24 hrs. × 0.746, at one cent	12,891.00
Wages, 4 men × 365 days, at $1.50 (2 men per shift)	2,190.00
Maintenance, lighting, oil	600.00
Bag renewals	850.00
Dust transportation, 5702 tons at 25¢	1,426.00
Water, 0.1 liter per cbm. of gas, 14 million gals., at $10.00	140.00
Steam, 10 kg. per 1000 cbm. 12,654 M. lbs. at 18¢	2,278.00
Total operating cost per year	$29,788.00

The gas cleaned per year amounts to 20,131,200,000 cubic feet, and the cost of cleaning 100,000 cubic feet will therefore be

$$\frac{\$29788.00}{201312} = 14.79 \text{ cents.}$$

It is stated that this dust has a value of $1.40 per ton, giving a revenue of 5702 × $1.40 = $7983.00 per year, and making the net operating cost $29788.00 – $7983.00 = $21805.00, thereby reducing the cost of cleaning 100,000 cubic feet of gas to 10.83 cents.

Plant No. 2. — Capacity: 1,695,000 cubic feet per hour, gas measured at 0° C. and 760 mm. pressure.

Cost of Installation

Apparatus, including reserve parts	$43,375.00
Steel structure for building, 55 tons at $65.00	3,575.00
Foundations, masonry, roofing	700.00
Motors and motor equipment, consisting of 2 of 150 H. P., 2 of 15 H. P., and 2 of 8 H. P., or 346 H. P.	3,750.00
Total cost of installation	$51,400.00

Note: — A dust conveyor is not included in this cost and the price for the motors seems low.

Cost of Operation

Amortization (10 %) and interest (5 %) on $51,400.00	$7,710.00
Power, 150 H. P. per hr. at 1 cent per K. W. H.	9,540.00
Wages, 4 men, two men per shift	2,190.00
Maintenance, lighting, oil	600.00
Bag renewals	1,155.00
Dust transportation, 4280 tons	1,070.00
Water, 10.5 million gallons, at $10.00	105.00
Total operating cost per year	$22,370.00

The gas cleaned per year amounts to 14,645,000,000 cubic feet, and the cost of cleaning 100,000 cubic feet will therefore be

$$\frac{\$22370.00}{146450} = 15.27 \text{ cents.}$$

If the value of the dust is deducted from the operating cost, or if $\$22370.00 - (4280 \times \$1.40) = \$16378.00$ is the net cost of operation, the cost of cleaning 100,000 cubic feet will be

$$\frac{\$16378.00}{146450} = 11.18 \text{ cents.}$$

Plant No. 3. — Capacity: 1,059,000 cubic feet per hour, gas measured at 0° C. and 760 mm. pressure.

Cost of Installation

Apparatus, including reserve parts	$33,625.00
Steel structure for building, 40 tons at $65.00	2,600.00
Foundations, masonry, roofing	750.00
Motors and motor equipment	3,500.00
Dust conveyor, etc.	500.00
Total cost of installation	$40,975.00

COST OF OPERATION

Amortization (10%) and interest (5%) on $40,975.00	$6,146.00
Power, 105 H. P. per hour = 676,771 K. W. H. at one cent	6,768.00
Wages, 4 men, two men per shift	2,190.00
Maintenance, lighting, oil	450.00
Bag renewals	720.00
Dust transportation, 3421 tons at 25 cents	855.00
Water, 6.5 million gallons at $10.00	65.00
Total operating cost per year	$17,194.00

The gas cleaned per year amounts to 9,149,760,000 cubic feet, and the cost of cleaning 100,000 cubic feet will therefore be

$$\frac{\$17194.00}{91498} = 18.79 \text{ cents.}$$

Deducting the value of the dust, we will have as the net operating expense $17194.00 – (3421 × $1.40) = $12405.00, making the cost of cleaning 100,000 cubic feet of gas

$$\frac{\$12405.00}{91498} = 13.55 \text{ cents.}$$

It will be noted that the cost of steam is not given for Plants Nos. 2 and 3; this would add to the total cost of operation. The cost of installation only applies to European conditions, and in America they would be somewhat higher, due to the higher cost of both material and labor.

In order to give some idea of the dimensions required in an installation of this character, and as the bag-house system has not as yet been operated in America in connection with a steel blast-furnace, a description of a bag filtering plant in connection with the copper and lead industry is given below.

The "Murray" bag-house of the American Smelting and Refining Company was placed in service in 1907, and its original cost, including building, bags, distributing flue, fan, fan house, motors, and one hundred feet of brick flue measuring 17′ 0″ by 16′ 0″, was $127,195.00, the building being 216′ 6″ long by 90′ 6″ wide, and 51′ 6″ high to the roof trusses, occupying 19,595 square feet of ground area. The house is divided into four compartments, each compartment being sub-divided into four chambers, under which are a total of sixteen cellars communicating by means of bull's-eye valves with the distributing flue running along the entire length of the house, this flue being built of brick.

The gases entering the flue are subjected to previous air cooling by being passed through special steel cooling flues leading from the furnaces. The floor of the filtering chambers, located above the cellars, is provided with a series of thimbles, each filtering chamber containing 1008 thimbles which are riveted to the steel floor and which surround the 17 inch diameter openings in the floor; the lower ends of the bags, which latter measure 18 inches in diameter and are 30 feet long, are securely clamped to these thimbles, the upper closed ends being suspended from a shaking rack.

It will be seen that the bags are much larger than those usually provided in the Halberger-Beth system, this larger size greatly reducing the multiplicity of operating parts. As the dust collected in the cellars of this house must be sintered for further treatment, each cellar is periodically shut off from the filtering chambers, the entire system therefore not being available for gas cleaning at any one time. From the description of the Halberger-Beth system it will be seen that a periodical shaking and filtering also exists, and consequently the entire bag system will also in this case not be available for filtering during the entire operating period.

Five hundred and seventy thousand and twelve (570,012) square feet of bag filtering surface is provided at Murray for the cleaning of 165,000 cubic feet of gas per minute, or at the rate of 3.45 square feet of bag surface per cubic foot of gas per minute, but this entire surface is not available for filtering at any one time, as when one compartment is shut down for sintering only 2.59 square feet of filtering surface per cubic foot of gas per minute will be available; therefore in determining the number of bags required for the above volume of gas, 2.5 square feet of filtering surface per cubic foot of gas per minute was allowed.

The original cost of this house per 1000 cubic feet of gas per minute was $770.88, but this cost was soon increased, as it was found that the cotton bags originally furnished had but a very short life, and they were replaced by woolen bags, the cotton bag costing $2.14 each, while the price of the woolen bag was $4.72, a total of 4032 bags being required.

The total price of the house with woolen bags was $137,607.00, or $34.13 per bag, and $834.00 per thousand cubic feet of gas per minute.

The amount of gas handled per bag per minute is $\frac{165,000}{3024} =$ 54.56 cubic feet, and the efficiency of the Murray house is from 85 to 90 percent, while the efficiency of a bag filtration plant on steel blast-furnace gases should be at least 98 percent, as the bags will not be affected by the acids contained in copper or lead fumes.

An exact cost comparison between the Halberger-Beth plants and the one at Murray cannot be given, because the cost of the pre-cooler, re-heater, and final coôler are not given separately, and a portion of this apparatus would have to be added to the Murray house in order to arrive at a complete unit price; besides this, the unit price of $834.00 per thousand cubic feet of gas passed, amounting to 165,000 cubic feet per minute at Murray, would have to be increased, owing to the lesser capacity given in the three examples, the largest of which only passes 38,834 cubic feet of gas per minute, or about one-quarter the quantity passing through the Murray house.

THE BAG-HOUSE VERSUS THE "WET" SYSTEM

The bag-house has proven effective in controlling the fumes from copper and lead blast-furnaces and from copper converters, and with very few exceptions the various constituents of these fumes have been removed to a greater or lesser extent, but the sulphur dioxide present and which is a very volatile vapor, has defeated all attempts to completely remove it before the gases escape into the atmosphere, causing the agriculturists in the neighborhood of the smelter to assume a very hostile attitude.

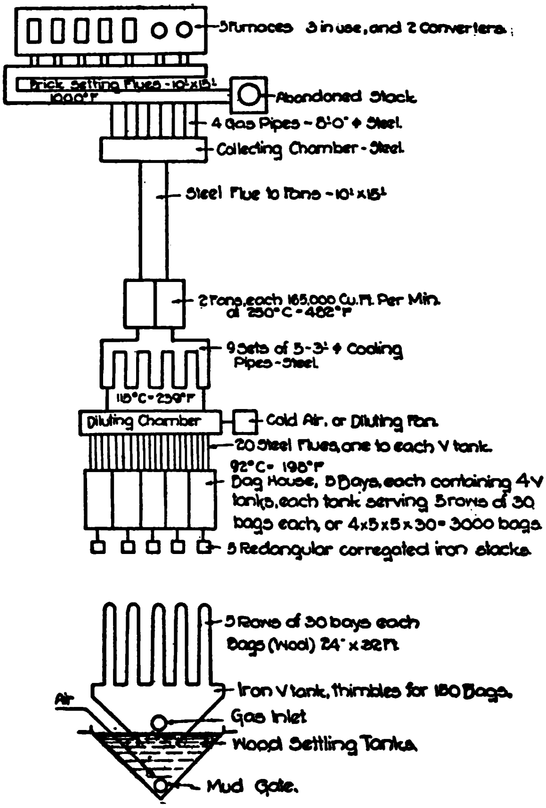
The bag-house, as well as electrical precipitation plants, have been successful to a certain extent in removing the solids from fumes by mechanical means, but these mechanical devices have been unsuccessful in handling sulphur dioxide gas, and as this constituent of the fume is one of the principal sources of damage to surrounding vegetation, the importance of its control is appreciated by the copper smelter, the laws of the state of California requiring that the sulphur dioxide content be reduced to a maximum of three-quarters of one percent before the gases are admitted into the atmosphere.

The most pressing question before the copper smelter has therefore been to so control the fumes as to facilitate the operation of the smelter, and consequently the removal of the solids through the medium of the bag-house, or similar device, and to dilute the gas with free air to a degree sufficient to meet the requirements of the law before transmitting it to the outer atmosphere.

The bag-house of the Mammoth Copper Mining Company, at Kennet, California, is an example of the best practice of its kind today, and since its installation very little interference has been met with from the neighboring agriculturists, while the electrical precipitation plant at the Balaklala smelter, at Coram, California, but a few miles below Kennet, was abandoned after a few months trial; this latter system has been greatly improved since its installation at Coram, but no claims regarding the removal of sulphur dioxide have ever been made for it, its only function being the removal of solid matter.

The introduction of the Feld centrifugal washer system causes this problem to assume quite a different aspect, as this washer will remove up to 98 or 99 percent of the solid content of the gas in one washing, besides presenting a ready means of absorbing the sulphur dioxide and thus removing this disagreeable and often costly feature of smelter operation, and in the Engineering and Mining Journal of Aug. 6, 1910, Mr. R. R. Moore, Consulting Mining and Metallurgical Engineer to the Mexican-American Holding and Improvement Company, says "personally I am opposed to the bag-house system for handling the fume from converters as wrong in principle and costly at the best in practice," and suggests treating the gases by some "wet" system; but the use of this dry method in lead, copper, and zinc smelting is a deep rooted evil, due to the fact that the operator must come in contact with dry dust which proves to be anything but beneficial, and the entire tendency since the introduction of the bag house has been to improve the evil instead of discarding it for something better, such as a wet system where personal contact with dry dust is impossible.

It is stated that the Kennet plant produces about thirty tons of blister copper per day, operating three furnaces and two converters, and thus produces about 330,000 cubic feet of gas per minute at a temperature of 250° C. (482° F.). This temperature and volume is measured directly in front of the two hot fans, each fan having a capacity of 165,000 cubic feet per minute, the general arrangement of the gas treating plant being shown on the flow sheet, Figure 34.


5 Furnaces 3 in use, and 2 Converters.
Brick Setting Flues - 10'x15'
1000°F
Abandoned Stack.
4 Gas Pipes - 8'-0" ⌀ Steel.
Collecting Chamber - Steel.
Steel Flue to Fans - 10'x15'
2 Fans, each 165,000 Cu. Ft. Per Min. at 250°C - 482°F
9 Sets of 5-3' ⌀ Cooling Pipes - Steel.
115°C - 239°F
Diluting Chamber
Cold Air, or Diluting Fan.
20 Steel Flues, one to each V tank.
92°C - 198°F
Bag House, 5 Bays, each containing 4 V tanks, each tank serving 5 rows of 30 bags each, or 4x5x5x30 = 3000 bags.
5 Rectangular corregated iron stacks.
5 Rows of 30 bays each
Bags (Wool) 24" x 32 Ft.
Iron V tank, thimbles for 150 Bags.
Air
Gas Inlet
Wood Settling Tanks.
Mud Gate.

FIGURES 34 and 35. — Flow Sheet of Kennet Cleaning and Diluting Plant

The bag-house is divided into five bays, each bag containing six hundred bags, or a total of 3000 bags to the house. "V"-shaped steel tanks, or hoppers, Figure 35, are located below the bag thimble floor, each hopper receiving the dust from five rows of thirty bags each, four of these hoppers being placed in each bay of the house; the hoppers are open at the bottom and their lower edges are sealed in water contained in "V"-shaped wooden vats, Figure 35, the gas being admitted into the steel "V" hoppers from whence it passes up and through the bags, the latter being about 24 inches in diameter and 32 feet high, made of wool.

The bags are shaken periodically, the automatic shaking mechanism giving the bag a sudden up-and-down movement of several inches; the dust is thus removed from the bags and thrown down through the steel hoppers into the water troughs, the clear water being drawn off every four or five days, after which the mud in the bottom of the tank is agitated by means of an air hose and thus caused to flow out into a settling tank where it is concentrated, and then finally drawn off to the final depository. The mud recovered by this method has no value at present, as no means has as yet been devised which would make a paying proposition of its operation, a solution to this problem having been left to future investigators.

The gas, before entering the house, passes through a series of cooling pipes, where the temperature is reduced to about 115° C. (239° F.), and thence into a diluting chamber where, through the medium of a fan, air is added in sufficient quantities to reduce the acid content of the gas to less than three-quarters of one percent.

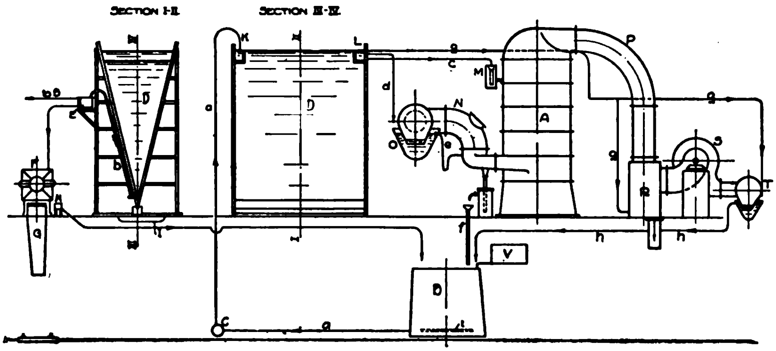


FIGURE 35a.—Feld Continuous Metal Dust Recovery Plant

The power cost for operating the two hot fans and the one diluting fan amounts to from $115 to $125 per day, based on a cost of $\frac{3}{4}$ cent per K. W. H., the hot fans operating under about a five-inch water column, and the cold fan under about four inches. This plant requires eight men, besides the foreman, for its operation, the cost of labor being about $26.20 per day, but this cost does not include the labor required for cleaning out the dust and mud.

It is stated that the entire plant, including gas mains, collecting chamber, flue, hot fans, cooling pipes, diluting chamber, cold air fan, distribution flues, bag-house, bags, and stacks, cost approximately $250,000; the bag-house and the five stacks are of corrugated iron construction.

A Feld cleaning system arranged to accomplish the above, but in a "wet" manner, is shown in Figures 35 A to 44, inclusive.

REFERRING TO THE FIGURE 35 A

A = Gas Washer,
B = Collecting Tank,
C = Wash Liquor Pump,
D = Separating Tank,
E = Overflow Trough for Concentrated Sludge,
F = Filter Press,
G = Chute for Press Cake,
H = Draw-off Trough for Clear Liquor from Filter Press,
I = Draw-off Trough with Filter, under Separator (*D*),
K = Delivery Trough at Separator,
L = Overflow Trough from Separator,
M = Water Seal for Liquor in Washer,
N = Raw Gas Inlet Connection,
O = Hydraulic Seal at Gas Inlet,
P = Clean Gas Main,
R = Connection Chamber between Washer (*A*) and Exhauster (*S*)
S = Gas Exhauster,
T = Clean Gas Collecting Main to Stack,
V = Lime Mixing Tank (if such be required),
a = Wash Liquor Connection to Inlet Trough (*K*),
b = Outlet for Concentrated Sludge from Separator (*D*) to (*E*),
c = Outlet Connection for Clear Liquor from (*L*) to (*M*),
d = Overflow Connection for Clear Liquor to Raw Gas Connection from (*L*) to (*O*), provided with Water Seal,
e = Overflow Connection from (*O*) to Washer Inlet (*A*),
f = Outlet Connection for Wash Liquor from Washer (*A*) to Tank (*B*),
g = Overflow Connection for Clear Liquor from Overflow Trough (*L*) of Separator to Connection Chamber (*R*) and Collecting Pipe with Water Seal (*T*),
h = Overflow Connection from Connection Chamber (*R*) and from Collecting Pipe with Water Seal (*T*) to Tank (*B*),
i = Steam Coil for heating washing fluid in Tank (*B*).

The gases from the furnaces enter the Feld Washer (A) at the hot fan temperature, or at 250° C. (482° F.), and are drawn through the washer by means of the exhauster (S), leaving the plant through the clean gas main (T).

The hot washing medium enters the washer at (M), the dust laden water leaving the bottom of the washer and flowing into the seal at (f), and from there into the collecting tank (B). This tank is supplied with an agitator in order to prevent a settlement of the solids and a possible clogging of pumps and pipe connections.

The sludge liquor from tank (B) is pumped by Pump (C) to the Sludge Separator (D) where the metal sludge is separated from the water, and automatically flows through the Goose Necks (b) into the Trough (E), and from thence to the Filter Press (F).

The filter press is only required if the dust to be recovered has a commercial value; if this is not the case the sludge from the separator can be carried to a final depository.

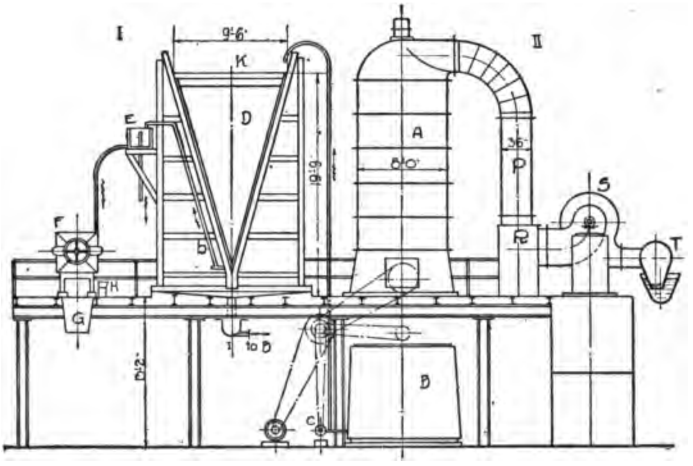


Figure 36.—Feld Recovery Plant. Capacity: 10,000 cubic feet of Gas per minute at 15° C.

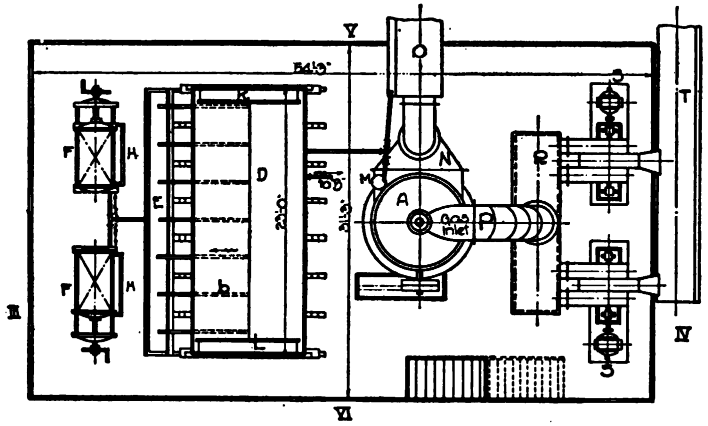
The clear water from the filter press flows from Trough (H) to Tank (B), while the cleared water from the Separator (D) flows partly to the Gas Inlet Trough (O), and partly to the Washer (A).

The water from Trough (O) enters the Seal at (f) through the gas inlet; the sludge collected in the filter press can be loaded into cars, or any other transporting medium, through the chute (G).

If the sludge has a commercial value it can, in its moist condition, be added to the material charged to the furnace, while if this should be attempted with the dry dust coming from the dust cellar of a bag-house, a large portion of the latter dust would be immediately carried away by the furnace gases and sent back to the bag-house, thus increasing the burden on this apparatus. Briquetting is not necessary, as the sludge leaves the filter press in the form of a cake which can readily be charged to the furnace.

The Feld system, from a hygienic standpoint, is of great benefit to the operator when compared to the detrimental effect of handling dry dust, as is done in some bag-houses, and as is the case in the Halberger-Beth system.

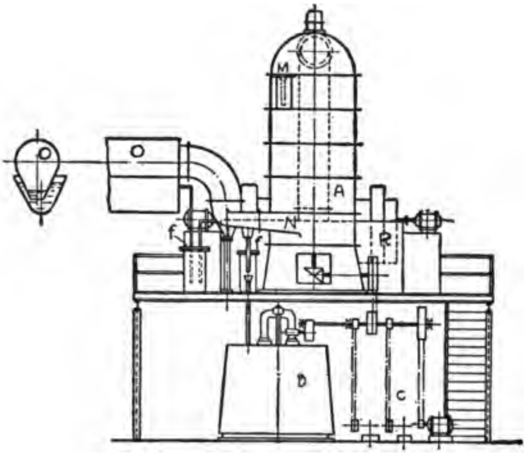
The sludge separator, Figure 43, is for the purpose of producing a continuous separation of sludge, and consists of an acute-angled vessel made of wood, the inside of which may be lined with thin sheet lead in order to increase the life of the apparatus, and also to assist in preventing possible leaks.



PLAN I-II

FIGURE 37.—Feld Recovery Plant

The liquid enters the trough (a) and spreads uniformly over its entire length, the elevation of the trough being dependent upon the liquid level desired. The separator, which must always be kept full of liquor, is provided at the top with several cross-pieces to which broom corn is attached, this latter serving the purpose of preventing any undue motion of the surface liquid. This broom corn serves the further purpose of retaining the froth, which latter contains an appreciable amount of metal dust gathered on the surface of the liquid, thus causing this dust to settle. The cleared liquid leaves the separator on the opposite side through trough (b), this latter trough being on the same level as the one at (a).



SECTION V-VI

FIGURE 38.—Feld Recovery Plant

The heavy sludge settles to the bottom and is forced through the goose necks (c) by the water head in the separator, the goose necks thus continuously delivering the sludge to the trough (d); from (d) the sludge enters the filter press under a pressure of from 39 to 78 inches of water, which pressure is sufficient to fill the press, but if a firmer cake is desired the liquid may be pumped into the press under a higher pressure.

In order to preserve proper operating conditions, care must be taken to see that the separator is always full of water; this is accomplished by supplying the outlets of the goosenecks with conical wooden stoppers, the bore of the opening in the stoppers being determined experimentally to suit the particular liquid in question; in other words, the separator must be so operated that clear water flows over in a continuous stream, all goose necks at the same time delivering a continuous stream of sludge, otherwise it will be difficult to avoid stoppages.

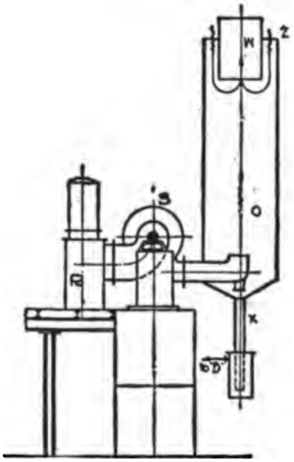
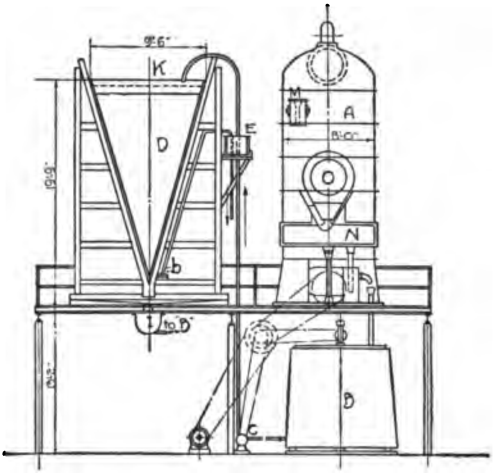


FIGURE 39.—Feld Diluting Stack



SECTION III-IV.

FIGURE 40.—Feld Recovery Plant

The wooden stoppers are shown in detail at (e) in Figure 43 and good operation demands that a number of these stoppers of various bores be kept on hand in order to accommodate the sludge flow to a possible difference in the composition of the sludge. The outlet nozzles of the goose necks are bent around so that they will deliver the sludge in the direction of flow in the trough (d), as this aids in carrying away any possible thick scum which might otherwise gather in the trough; it also prevents any possible splashing, and enables the operator to replace a wooden stopper without difficulty.

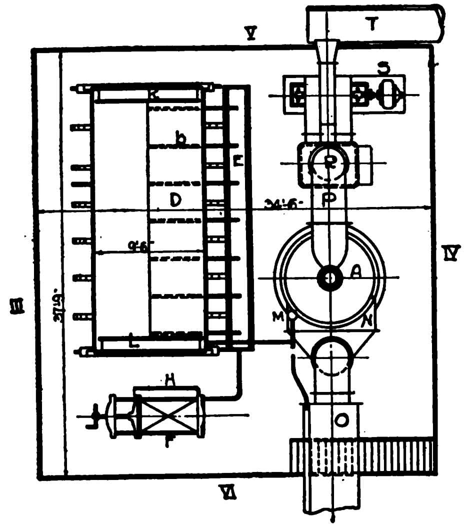
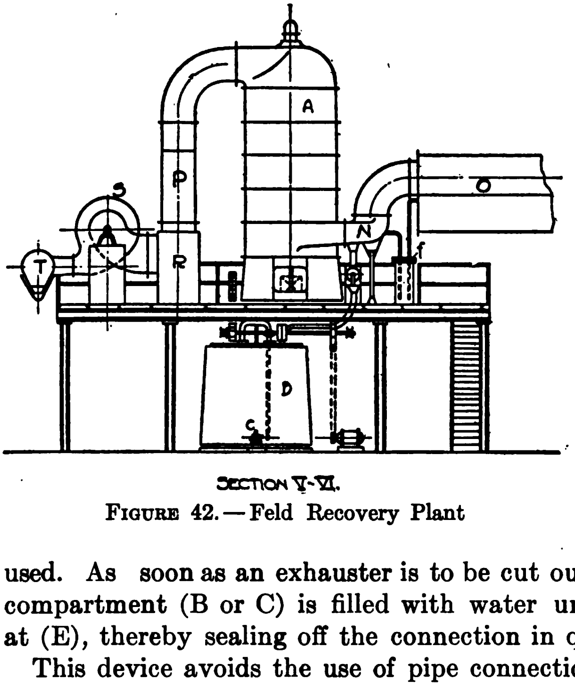


FIGURE 41.—Feld Recovery Plant

The separator should be erected with a fall towards one end so that it can be completely emptied into a sludge collector, and from thence through a filter to the collecting tank (B), in case repairs should at any time be necessary.

If the plant is supplied with two exhausters, as shown in Figure 37, a double connection chamber made of steel, and shown in Figure 44, is placed between the washer and the exhausters. The gas enters this chamber at (A) and is drawn through the device by means of the exhauster connected to the rectangular openings marked (D); the second exhauster, connected to the chamber at (D_1), is by-passed by means of the water seal at (B). If it should be desired to shunt out the (D) exhauster and operate the one at (D_1), the water is admitted at (H) and shut off at (H_1), draw-off valve (K) being opened and the one at (K_1) closed, thus causing a continuous flow of water to pass through the sealed-off portion of the chamber. This water seal is established by means of the two partitions, marked (F) and (G), which are open at the bottom, and the one marked (E), which is open at the top.



SECTION V-VI.

FIGURE 42.—Feld Recovery Plant

This chamber serves the following purposes:

(1) It retains any water particles which might be carried forward by the gas coming from the washer, and

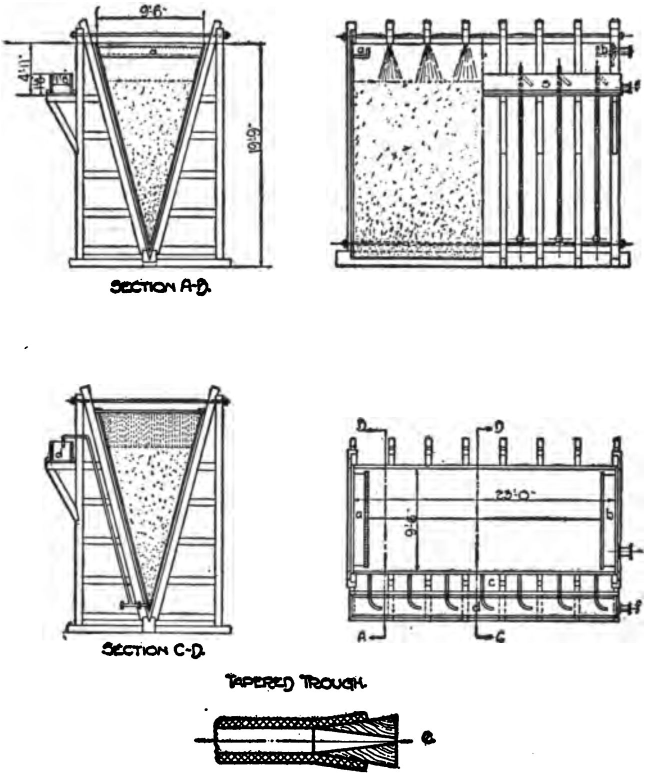
(2) It serves as a much more satisfactory cut-out than if valves were used. As soon as an exhauster is to be cut out the respective compartment (B or C) is filled with water until it overflows at (E), thereby sealing off the connection in question.

This device avoids the use of pipe connections between the washer and the exhauster, thus cutting down the possibility of disturbances due to clogged pipes, the water supply to the chamber being taken from the washer through funnels (H) or (H_1).

Before starting operation the separator (D) must be filled with hot water, and it is of extreme importance to avoid having the raw gas entering the washer come in contact with cold water, as if this should happen it would be impossible to prevent clogging the passages inside the washer.

The water in tank (B) should be heated by means of the steam coil (i), after which the hot water is delivered by pump (c) to the separator (D), this cycle being continued until the separator is completely filled. The temperature in (D) must not fall below 70° C. (158° F.).

The hot water overflow from the separator fills the washer (A) and finally flows from the washer through the seal at (f) into the tank (B), and after the latter is half filled with water from this overflow, the washer is started and the gas turned in, care being taken never to turn gas into the washer until after the latter has been operated under a full load of water. In this manner the various chambers of the washer are filled with hot water, and pump (c) then continuously delivers hot water from tank (B) to the separator (D).



SECTION A-B.

SECTION C-D.

TAPERED TROUGH.

FIGURE 43.—Feld Sludge Separator

As another example showing the difference between the "dry" and "wet" systems, the lead mines and smelters at Mechernich-on-the-Rhine, Germany, may be mentioned. A four percent lead ore is worked up at this plant, and the fumes from the furnaces were formerly conducted through five immense galleries, or tunnels placed under ground and leading to a stack. The total length of these galleries amounted to 1.25 miles, while the chimney at the end had a height of 428 feet.

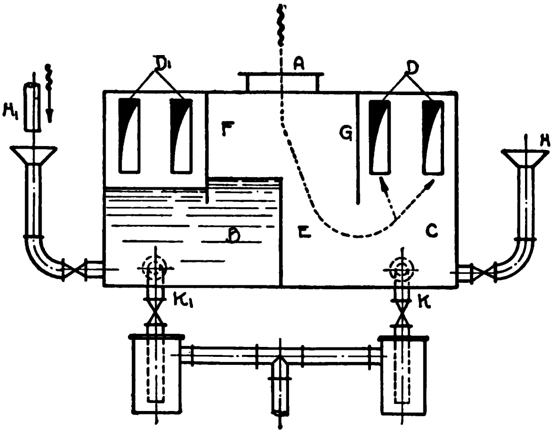


FIGURE 44.— Connection Chamber

In spite of these galleries, or settling chambers, the gases leaving the chimney inundated the surrounding country with their dust content to the detriment of both animal and vegetable life. Twice a year, consuming a period of three weeks each time, the entire plant was shut down to permit of cleaning out these galleries, the dust being removed by means of wheel-barrows and carts, each occasion leading to physical ailments among the laborers, and sometimes loss of life, due to contact with the dry lead dust. In order to obviate this nuisance, and to recover the lead lost through the stack, a "wet" system of the Feld type and similar to the one described above, was constructed, two Feld washers working in series, each supplied with a ventilating fan, being installed.

It is claimed that during every 24 hours of operation while the Feld plant was in service this apparatus recovered on an average of six tons of dust containing from 80 to 90 percent of lead and the nuisance was entirely removed, while an efficiency of 99.87 percent was secured. The mud flowing from the bottom of the washers was forwarded by means of rotary pumps into an elevated settling basin, or separator (D), built of wood as explained above; the syphon overflows drew the heavy sediment from the bottom of the separator and delivered the mud to the filter press where the moisture was extracted, the resultant filter cake being again charged into the furnaces; in this manner this plant was made one of continuous operation, instead of an intermittent one as had formerly been the case.

Fifty tons of lead were smelted per day, producing about 35,000,000 cubic feet of gas containing about eight ounces of lead per 1000 cubic feet; due to leakage through the walls of the flues this quantity of gas was increased to about 71,000,000 cubic feet, and the gases leaving the chimney contained about one ounce of lead per 1000 cubic feet, the total loss through the chimney being estimated at two tons per day. The value of this loss was about $100 per day, while the operation of the entire Feld system, including labor, power, supplies, repairs, interest and depreciation only amounted to about $50 per day, leaving a net profit of $50 per day due to the "wet" installation. This plant has been closed down owing to lack of ore.

As stated before, these cleaned gases as they leave the exhauster usually contain SO_3 as well as SO_2, and two methods of treating the gas for these deleterious constituents are suggested by the Feld system, the first one calling for admittance of the cleaned gas into a large wooden stack (O), the upper portion of the stack being supplied with a wooden insert (W) of cylindrical shape. The exuding gases under this condition, providing they are not cooled below a temperature somewhat higher than the surrounding atmosphere, will draw a large quantity of air from the atmosphere into the stack through the annular passage (Z), Figure 39, thus reducing their density and unit acid content and making them harmless.

The condensed liquid from this stack is collected at the bottom and flows through the outlet connection (X) to the tank (B). The insert (W) should have a cross-sectional area of about twice that of the exhauster outlet (S), so that the gases will enter the atmosphere at about one-quarter of their original density, the area of the insert also being dependent upon the amount of acids present in the gas.

If the SO_2 and SO_3 constituents are of such quantity that the gases cannot very well be diluted by the above mentioned method, these acids may be neutralized by adding lime to the wash water, or

$$CaO + H_2O = Ca(OH)_2,$$

calcium-hydrate, or slaked lime being used, its suspension in water resulting in "milk of lime."

This milk of lime in the washer produces two reactions,

$$\text{(I)} \qquad Ca(OH)_2 + SO_2 = CaSO_3 + H_2O,$$

or calcium-sulphite is formed; and

$$\text{(II)} \qquad Ca(OH)_2 + SO_3 = CaSO_4 + H_2O,$$

or calcium-sulphate is formed.

We will assume that the gas contains one percent of SO_2 per 1000 cubic feet per minute, as this figure can readily be converted for any other amount present.

One thousand cubic feet by 1% = 10 cubic feet of SO_2, and as at 60° F. and 30″ barometer there are 5.9 cubic feet of SO_2 to the pound, there would be

$$\frac{10}{5.9} = 1.7 \text{ pounds of } SO_2 \text{ per 1000 cubic feet}$$

of gas.

This would give, with

$$\begin{array}{l} Ca(OH)_2 + SO_2 = CaSO_3 + H_2O, \\ \quad 74 \quad\; + 64 \end{array}$$

and as 64 pounds of SO_2 require 74 pounds of $Ca(OH)_2$ for neutralization, one pound of SO_2 to 1.15 pounds of $Ca(OH)_2$, or $1.7 \times 1.15 = 1.95$ pounds of $Ca(OH)_2$ per 1000 cubic feet of gas per minute, or
$1.95 \times 0.7566 = 1.47$ pounds of CaO per thousand cubic feet, with an additional allowance for neutralizing the SO_3 present, one pound of SO_3 requiring about 0.9 pound of $Ca(OH)_2$.

Applying these amounts to a blast-furnace gas containing 0.06% of SO_3 and 0.16% of SO_2, or a total of 0.22% of acids, the quantity of lime required would be about 0.5 pound per 1000 cubic feet.

If sodium-carbonate or soda-ash is used, 2.8 pounds would be required per 1000 cubic feet of gas with one percent of SO_2 present, and the operation would be somewhat simplified.

Reverting to the Kennet bag-house it will be noted that the gas to be treated amounts to 330,000 cubic feet per minute at 482° F., which reduced to 60° F. or 15° C. will be

$$\frac{(459.2 + 60)\ 330000}{459.2 + 482} = 182{,}000 \text{ cubic feet,}$$

or 182,000 × 1440 = 262,080,000 cubic feet, or 742,500 cubic meters per day.

This amount of gas will require eight washers of the H_1 size, or of 10′ 0″ diameter.

In order to reduce the volume of gas to be handled by the fan, the temperature can be reduced to about 25° C., or 77° F. It is assumed that the gas carries a maximum water vapor content of 120 grammes per cubic meter, and that the inlet temperature of the wash water is 20° C., which temperature is to be increased to 75° C. at the overflow.

The heat to be extracted from the gas will then be
$95.5 + 0.389\ (250 - 52) - 24 = 148.5$ calories per cubic meter, and the quantity of water required will be

$$\frac{148.5}{75 - 20} = 2.7 \text{ liters per cubic meter,}$$

or 19 to 20 gallons per 1000 cubic feet.

The volume of gas to be handled by the fans will be

$$\frac{(459.2 + 77)\ 330000}{459.2 + 482} = 187{,}000 \text{ cubic feet}$$

per minute, or, using one fan to each washer,

$$\frac{187000 \times 60 \times 24}{8} = 33{,}660{,}000 \text{ cubic feet}$$

per day per fan at a maximum of three inches of water pressure, each fan requiring about 40 horse power, while each washer will require about 35 horse power.

The operating expense will then be:

Washer Power: 8 × 35 × 24 × 0.746 @ 0.75¢ per K. W. H.	$37.60
Exhauster Power: 8 × 40 × 24 × 0.746 @ 0.75¢ per K. W. H.	42.97
Water: 20 × 330 × 1440 @ $10.00 per million gallons, but only about 10 % of this will be used per day, as the water is returned to the washer	9.50
Labor: 2 Foremen @ $3.75	7.50
" 6 Laborers @ $2.50	15.00
Maintenance, Oil, Waste, etc.	5.00
Total operating cost per day	$117.57

as compared with $146.20 per day under present conditions of operation at Kennet, giving an annual saving of $10,450, or 6% on $175,000.

In order to show the hygienic advantages to be secured by the Feld " Wet" system over the usual bag-house system as practiced in the lead smelters, reference is made to Bulletin No. 141 of the U. S. Department of Labor, Bureau of Labor Statistics.

We here find a statement to the effect that the prevention of fumes and dust in American smelting plants leaves much to be desired, and yet this same fume and dust is responsible for the great majority of cases of industrial plumbism, and their control should be a simple matter compared to the complicated engineering problems which have been successfully solved by smelting experts. Too much insistence is placed upon the responsibility of the workman for his personal cleanliness and too little on the responsibility of the management for the conditions under which the man works.

The Department notes 1769 cases of lead poisoning in the year 1912 among 7400 men employed in 19 plants, but this number hardly represents the total number of cases, as few of the plants kept full medical records, and the number of cases found probably falls far below the truth.

This report further informs us that the dust and fume collection system in a modern American smelting and refining plant is very large and elaborate; usually, as stated above, steel flues pass from the roasters and blast furnaces into large brick flues, finally terminating in the bag-house. These steel flues are usually provided with some arrangement for allowing the heavier flue dust to be removed, such as doors, which permit the flue cleaner to insert a bent hoe or rake and to scrape out the dust, or, if the flue is very large, permit him to enter and shovel it out. At other plants the flues are provided with hoppers ending in a gate, so that the latter may be opened and the deposited dust drawn off into cars. Brick flues are provided with doors for the same purpose, while the very light dust passes on to the bag-house.

This flue dust is a bluish-black powder, light and fluffy, consisting chiefly of the oxides and sulphate of lead in varying proportions, and also of arsenic if the smelted ore contained arsenic.

Brick flues are always emptied by the workman entering the flue and removing the dust with a shovel, while in the bag-house the bags are shaken by hand in some plants, by mechanism in others, and in a few the dust is dropped by occasioning a vacuum in the house, thus making the bag collapse.

It is necessary to divide the bag-house into separate compartments for various reasons; i.e. — danger of fire, and, if the bags are all in one compartment, the necessity of daily shaking will put the house out of operation during this period, and thus disturb all draft conditions during this time. The removal of the dust from the cellars is done by sintering and then shoveling out the sinter, or the dust may be shoveled out without any previous treatment, but in either case the dust and fume is excessive, especially if the sinter or dust has not been cooled properly.

In the United States smelter at Midvale the SO_3 fumes are neutralized by a patented process of mixing the fumes with volatilized zinc oxide, thus forming zinc sulphate. In another plant the SO_3 is neutralized by the introduction of lime into the flues, which is also a patented process.

The report states that at Midvale the openings in the dust tunnels are connected with hoppers which catch the dust and discharge it into a screw conveyor, the latter delivering the dust to carts, thus obviating the necessity of a man entering the flue. The bags are shaken by reversing the current of air and causing a vacuum in one of the twelve compartments of the bag-house at a time. Bag repairing must be done at least once a day, but the compartment is always shut off and the windows opened before a man is permitted to enter. The large flues are cleaned once every six months by flushing them out by opening a hole in the top of the flue and a vent in the bottom, the latter leading to a large discharge pipe ending in a settling tank, water from a hose being directed into the flue through the top hole, thus washing out the dust.

In smelting and refining plants the flue and bag-house work is usually regarded as more or less an emergency task except for the men regularly employed for this purpose.

The report states that in the plants examined it is usual to clean the steel flues once in two to four weeks, the brick flues once in three to six months, and the bag-house tunnels once in four to twelve months, a special gang of laborers being collected for this work, the men being usually taken from the yard gang, unless a contractor from the outside brings in his own men. The work of cleaning must be rushed through as rapidly as possible, especially on the larger flues and the bag-house, because the shutting off of any considerable portion of the flue system interferes with the working of the furnaces. Thirty or forty men are usually put at work, and if the work is not being done by contract the men do not work long hours, sometimes only five hours per day. As to the sprinkling of the flue dust, one manager stated that while it was possible to sprinkle the bag-house dust, this was not so in the flues, because the dust in the latter is hot and the steam thus created would be excessive. The prevailing opinion is to the effect that if the sulphate in the flue dust is all combined, as is the case with the dust from copper converters and from white lead, it can be sprinkled without harm, but dust from reverberatory furnaces contains free SO_3 which would combine with the water and form sulphuric acid, this latter eating into the men's clothing and causing painful skin burns. The success of the Midvale system is due to the neutralization of the SO_3 as explained above. Even in such bag-houses and flues which receive only lead sulphate dust, without any free SO_3, the dust is sometimes handled in a dry condition, as dampening, or sprinkling is said to cause too much dust.

All of these troubles cited by the report mentioned above can be avoided by the use of a wet system such as the Feld, as in this case it is never necessary for the attendant to come in contact with dry dust, a wet cake, which can be handled without danger to health, being produced in the filter press.

The following tables have been extracted from the above mentioned bulletin in order to show the danger existing in the handling of dry dust from lead smelters.

Plumbism, Myalgia, and Indigestion

Year	Employees	Cases of			
		Plumbism	Myalgia	Indigestion	Total
1898	800 — 850	74	48	174	296
1899	800 — 850	74	47	242	363
1912	500 — 550	52	93	297	342

I would further quote as follows from the above mentioned bulletin:

"There is just one plant where records have been made of the physical condition of the men in the different departments showing which kind of work has the greatest attendant risk of lead poisoning. The figures given do not represent attacks of acute poisoning; they represent the number of men who, on medical examination, were found to show signs of chronic plumbism.

At the time the plant was visited, 232 men had been recently examined, but 42 of them had worked only one month or less than a month, and in the case of 16 the employment was not distinctly stated, leaving 174 men distributed as follows:

Cases of Plumbism, and Rate per 100 Employees in a Certain Plant Visited, According to Character of Work Performed

Occupation	Number Examined	Cases of Plumbism	
		Number	Rate per 100 Employees
Yard gang, unloading, wheeling charges, etc.	26	5	19.5
Furnaces	119	37	31.1
Bag-house and flues	8	5	62.5
Misc. refining, repairing, masons, etc	21	3	14.3

This was only about one-half the force, and the number of men under the different headings do not represent the actual proportion of men employed in the different departments, for they were not examined in any particular order. The blast-furnaces here are poorly hooded and dangerous, *but the flue and bag-house men are the worst sufferers in the plant.*

Another record which throws light on the danger of different kinds of work was kept during two months of 1913 in a plant employing regularly 622 men. Sixty-five cases of plumbism occurred in those two months. The men were employed as follows:

CASES OF PLUMBISM, AND RATE PER 100 EMPLOYEES, DURING TWO MONTHS OF 1913, BY DEPARTMENT

Department	Number Employed	Cases of Plumbism	
		Number	Rate per 100 Employees
Mills, crushing, sampling	42	6	14.3
Ore bins	45	6	13.3
Sintering	60	6	10.0
Blast-furnace feeding	35	7	20.0
Blast-furnace tapping	90	21	23.3
Settling furnace and slag dump	18	6	33.3
Converters	45	3	6.7
Miscellaneous	280	7	2.5
Bag-house	7	3	42.9

This would be high rates for a whole year, and this record covers only two months.

As will be seen from this latter record, the *bag-house is again responsible for the largest percentage of cases.*

A modification of the Halberger-Beth system is **known** as the

Smith-Bagley System shown in Figure 45; this system is of English design, but it has as yet not been placed in operation on a sufficient scale to demonstrate its ultimate efficiency.

In the Smith-Bagley system the suspended canvas bags of the Halberger-Beth are displaced by traveling belts made of canvas. This process comprises a cooler (A), with gas inlet at (B) and outlet at (C), a housing (D) containing a series of enclosed vertical moving belts (E), with gas passages between them, a final cooler (F), and a fan (G).

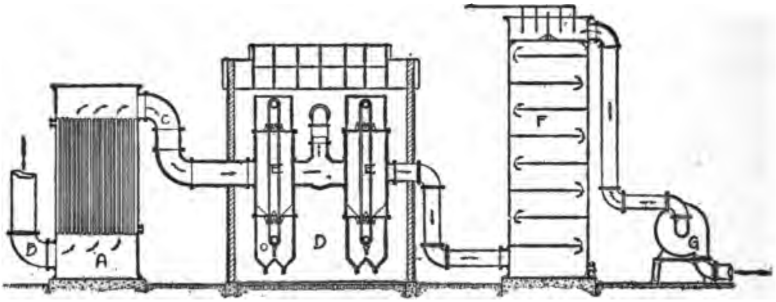


FIGURE 45.— Smith-Bagley Gas Cleaning System

After leaving the furnaces the gas enters a dry dust catcher from whence it is led into the primary cooler (A), where the temperature is reduced to the proper degree, the cooler being of the multitubular water type, so constructed that the amount of cooling surface can be increased or decreased automatically, the amount of surface used depending upon the inlet temperature of the gas. After the gas has been cooled it is admitted into the belt house, the gas impinging upon the enclosed vertical belt (E), the surface of these belts being dependent upon the gas volume and its composition, and besides a vertical travel, the belt is given a periodical shake by means of rollers so arranged as to increase the tension on the belt and then to suddenly release it.

The gas is caused to pass through the belt, it being so constructed that the gas cannot by-pass to the sides, and the dust is thus deposited upon the surface of the belts by impingement. The belts are kept in continuous motion, entering and leaving the casing through the medium of gas-tight rolls. A separator, containing a magnetic field, is provided at the points where the belt leaves the casing, any magnetic or metallic particles of dust being thereby withdrawn and deposited in a separate receiver, after which the belt continues on into a vacuum collector where the remaining dust is removed.

It is proposed to install a number of the vacuum collectors in series in order to completely remove the dust from the belt and thus again prepare it for cleaning purposes. A separate outlet is provided in the gas passage between the belts for taking off gas to be used under boilers and in hot-blast stoves, the gas for engine purposes passing through the second series of belts, and then on into the final cooler.

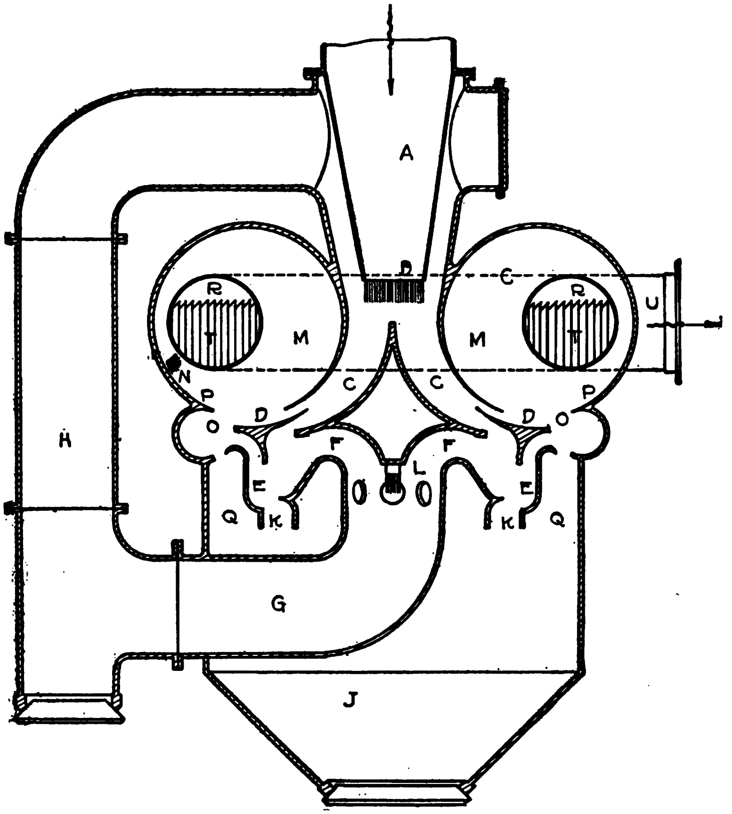


FIGURE 46.—Johnson Dry Cleaner

The Johnson Dry Cleaner. — This cleaner depends upon giving the gas a vortex or spiral motion in a closed vessel, causing the dust to move towards the periphery of the whirling gas and then skimming the outer stratum of the gas from the vessel, thus driving the dust off from the body of the gas by means of centrifugal concentration; besides this, the device makes use of electrical means to agglomerate the fine dust into larger particles so that they will more readily respond to the effect of centrifugal force and gravity.

As shown in Figure 46, the gas enters the cleaner through the central flue (A) and then passes an electrode (B), this electrode consisting of a copper bar carrying numerous fine points extending downwards, thus polarizing the dust particles by induction and agglomerating them by electric attraction. After passing the electrode, the gas enters the ring nozzle (C), the dust particles being thrown against the lower curved surface of the ring. That portion of the gas containing the greater amount of dust is caught under the knife-edge of the parting ring (D), where it is turned downward until it strikes the curved deflector ring (E), thence passing onward into the ring port (F), and then into the circulating elbow (G).

It is claimed that the gas contained in the dust chamber (J) is in a practically static condition, and exerts a back pressure on the stratum of gas deflected by the knife-edge against the ring (E), this back pressure having a tendency to increase the deflection of the lighter and cleaner gas of the stratum toward the ring port (F), but separated dust will pass along the ring plate (E) into the dust chamber (J) by means of port (K), while the dirtier gas will tend to form eddy currents which will pass off through the port (F).

When the gas enters the circulation elbow (G) it is caused to pass the second electrode (L) which agglomerates the remaining dust, this dust being thrown down during its passage through the elbow and is collected at the bottom of the vertical flue (H). The gas now rises in (H), and again passes the electrode (B), where any remaining dust particles are thrown out and combined with the dust contained in the dirty gas entering the cleaner through the central flue (A).

The gas now again passes through the ring nozzle (*C*), but the clean gas is in an upper stratum, thus escaping the knife-edge, and enters the vortex chamber (*M*), where it rapidly circulates in the form of a vortex spiral. As the gas revolves in this chamber it is caused to pass the third electrode (*N*) where dust is agglomerated and thrown against the outer shell of the chamber. Here it is whirled around until it reaches the ring port (*O*), into which it is deflected by the knife-edge (*P*), entering the ring under port (*O*) and being swept around until it enters the dust chamber through port (*Q*). The cleaned gas now passes out of the vortex chamber through the opening (*R*), where it is deflected into the discharge chamber (*S*) through the medium of the vanes (*T*), finally reaching the outlet (*U*).

There are several serious objections to this device; clean, or partially cleaned gas is mixed with dirty gas coming from the furnaces, and the cleaner must be proportioned to take care of this extra volume. The danger of stoppages is very evident, as the movement of the dust in the various rings is entirely dependent upon the motion of the gas.

Another device which is very popular in chemical manufacture, and which has been proposed, but to my knowledge never been tried, for use in cleaning blast-furnace gas, is known as

The Howard Dust Extractor. — In this device the dust is deposited upon a series of iron shelves enclosed in a steel chamber, the shelves being made of No. 10 steel and placed about 2.5 inches apart, one being located above the other. The gas is caused to pass with a uniform flow between the plates, the dust being deposited upon the plates due to a check in the gas velocity by reason of the large cross-section of the passage. The dust soon builds up on these plates and must be removed periodically, a fact which does not recommend this device for the cleaning of blast-furnace gas.

There still remains another system of dust extraction which differs entirely from any of those described, but which has as yet not been applied to the gases from steel blast-furnaces, namely

The Cottrell Electrical Precipitation Process. — This process has been, and is used for the collection of sulphuric acid mist from parting kettles in silver refineries; for the recovery of the small amount of sulphuric acid usually carried away from acid concentrating stills; for removing the solid particles from the fumes of sintering machines or roasters; and for the extraction of dust from the stack gases coming from cement kilns. Experiments have been under way for some time in connection with the clarification of fumes and gases produced in other processes, and it is to be regretted that no data relating to its application to blast-furnace gas is at hand. This system is the invention of Dr. F. G. Cottrell, formerly of the University of California, but at present connected with the United States Bureau of Mines.

The principle upon which this system is based consists of subjugating the dust laden gases to the influence of a series of electrodes, some of which are arranged to maintain a "silent" or "glow" discharge; due to this discharge the space between the electrodes becomes filled with gaseous ions and the dust particles passing through this space become charged, due to the impingement of the ions upon them, thus imparting their ionic charges to the particles. The charged particles are then passed through an intense electric field which causes them to migrate in the direction of the field, which latter is usually arranged transverse to the direction of the flow of the gases. The dust particles are thus drawn out of the gases and deposited upon the electrodes, the gases being permitted to go their way unaffected and emerge from the treating apparatus freed from the solid particles which had been held in suspension.

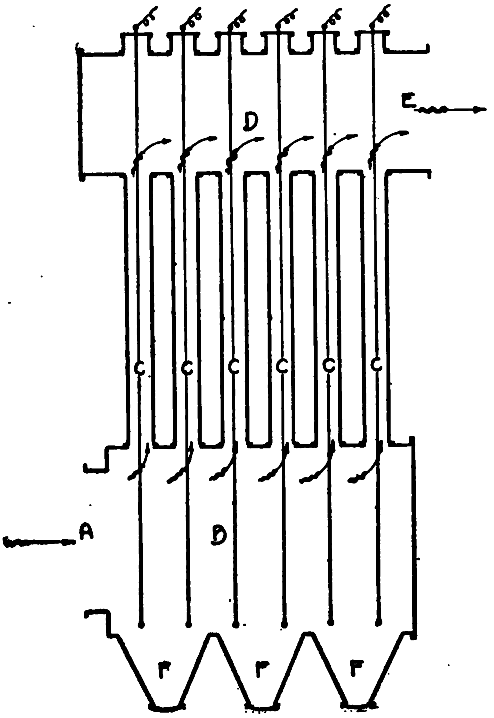


FIGURE 47.—Cottrell Electric Precipitator

The treating apparatus is very simple in construction, one of the simplest forms being shown in Figure 47, in which (*A*) is the gas inlet to a common distributing main (*B*), provided with cone bottoms and valves (*F*) for the removal of the precipitated dust; the gas from the distributing chamber (*B*) passes upwards through the cylindrical tubes (*C*) into the collecting chamber (*D*), and finally leaves the treater at the outlet (*E*). The electrode in this case consists of a wire conductor passing through the center of each of the tubes (*C*), one end of this wire being grounded.

The apparatus shown in Figure 47 is but one form of construction, and each problem presented may require a special form of treating chamber; the construction of the electrodes also varies considerably and they are usually made to suit the special conditions governing each problem. In this treating chamber the gas is permitted to pass unaffected while the solid particles are attacked individually by the electrical field and acted upon in such manner as to draw them out of the current of advancing gases and to precipitate them upon the collecting electrodes, the latter being represented by the walls of the tube (*C*) in the pictured construction.

In order to maintain a definite direction of migration of the dust particles, the electrodes must be given an unidirectional electrostatic charge, which is generated by rectifying a high tension alternating current. The voltages used range from 15,000 to 50,000 or more, depending upon the volume of gas to be treated, and upon its composition and condition.

In another form the electrodes consist of plates, or some other shape of light and heavy construction, the light discharge electrodes being so chosen as to maintain a heavy electrical discharge, while the collecting electrodes are of a heavy construction, their form and arrangement being such that no discharge can take place from their surface.

The discharge and the collecting electrodes are set alternately across the apparatus, a space of from two to six inches, depending upon condition, being allowed between electrodes. The dimensions of the treating chamber and the number of electrodes provided is proportioned to the amount of gas to be cleaned, the object being to pass the gas through at as high velocity and in as short a time as possible, in order to reduce the size of the apparatus as much as the desired efficiency will permit. The collecting electrodes are usually cleaned every three hours by means of rapping, but it has been found in installations treating perfectly dry gases that the dust settling upon the collector builds up at times and decreases the discharge space between the two electrodes with a consequent drop in efficiency.

In order to try and overcome this difficulty the electrodes have been given a maximum spacing with the idea that the dust will not build up beyond a certain distance and which contracted space will still maintain a perfect discharge. Saturated gases permit of easier treatment because in this case the moisture is thrown down with the dust particles, the liquid running down the collector and carrying the dust with it, thus cleaning the electrode and at the same time maintaining the proper discharge space.

Under any condition it has always been found that the selection of suitable electrodes has been of the utmost difficulty in attempting to produce a commercially valuable treater; the deposition of the suspended dust particles is greatly facilitated if the electric field terminals are of such nature as to provide sharp points or edges, even fine hair and similar bodies of very small electric discharge surfaces have been proposed for this purpose, or for discharge electrodes. Other difficulties have been encountered in attempting to arrange and suspend the electrodes for various purposes, for they should be so located and arranged as to produce rapid precipitation; besides this, the discharge electrodes must be of a material which will resist the deteriorating action of the gas, and in their structure they should if possible present the greatest number of fine discharge points, and as sheet mica is sufficiently non-inflammable, this material has in some cases given excellent results.

In consideration of all the difficulties which have been encountered in trying to adapt this process to various cleaning systems, careful experiments should be made to determine its adaptability to the cleaning of steel blast-furnace gas before an attempt is made to erect a commercial plant.

It is stated that one of the large blast-furnace plants is about to install a Cottrell plant for cleaning its gas, and the results of this installation are awaited with interest.

CHAPTER VI

OPERATIVE PLANTS IN AMERICA

Clairton. — The data given for this plant was secured while the Moyer Impinging Washer was being used, but this device has since been abandoned, and I understand that the United States Steel Corporation has discontinued the use of impinging washers in the entire Pittsburgh district, using various types of spray washer towers for primary cleaning, and it is therefore presumed that the impinging washer was not very successful. During the period that this washer was in use at the Clairton furnaces for primary cleaning, the cleaned gas contained an excessive amount of moisture, in fact it became necessary to fire the boilers with coal, abandoning gas fire in this instance, but the wet gas seemed to have but little effect upon the efficiency of the hot-blast stoves.

The general arrangement of the Clairton plant is shown in Figure 48, where the furnace is represented by (*A*), the down-comers by (*B*), the dry dust catchers by (*C*), and the Moyer washer by (*D*). The furnace is supplied with two down-comers (*B*), each about six feet in diameter, leaving the furnace at about thirty degrees with the vertical and entering the lower portion of the dry dust catcher (*C*) in a radial direction at a point about four feet above the bottom.

The dry dust catcher is designed to be a simple settling chamber of cylindrical form, measuring 10 feet in diameter by 22′ 6″ high, both the top and the bottom being frustums of cones. The gas leaves the catcher in the center at the top, and passes thence into the top of the Moyer washer. In the instance of Clairton this latter washer has a diameter of 26 feet and a height of 18 feet over the cylindrical shell, the bottom being conical and ending in a bell valve, this bottom cone being constantly supplied with fresh water, the surplus leaving through an overflow. The gas passes down through a central flue and impinges upon the surface of the water in the cone, the lower edge of this flue being from 1.5 to 5 inches above the surface of the water, this distance being regulated by the water overflow. The gas passes over the surface of the water, depositing a portion of its dust content and giving up a portion of its heat; it then passes upwards through an annular space and again descends, impinging upon the water a second time, finally passing up to the top of the washer and out at the sides. Both the dry dust catcher and the Moyer washer are provided with two side top outlets, one for conducting the gas to the boilers, and the other to the hot-blast stoves.

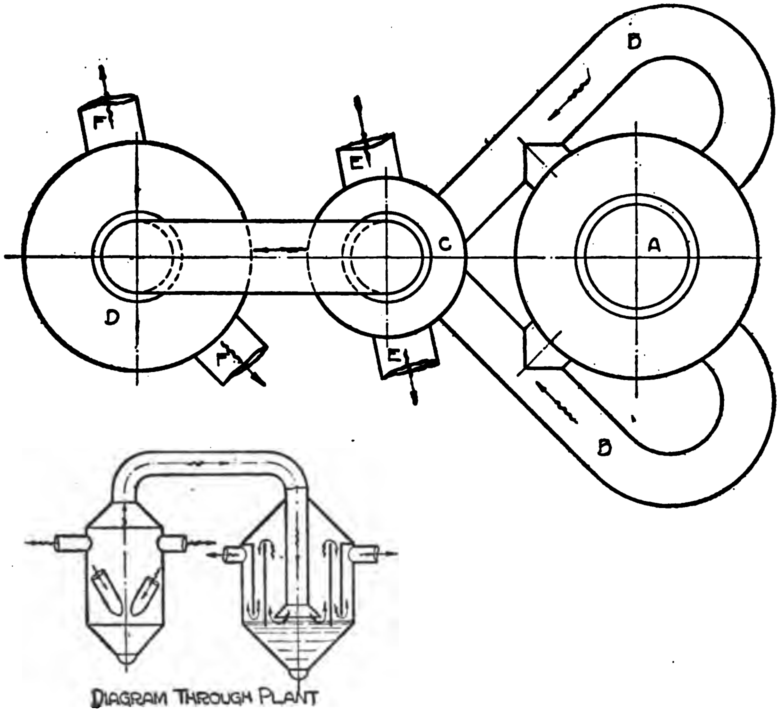


FIGURE 48. — Cleaning Plant at Clairton

The best work done with the Moyer washer was with a water level 1.5 inches below the central flue, as seen in Table VIII.

TABLE VIII. CLAIRTON RESULTS

Apparatus	Pressure in water inches	Temperature in degrees F.	Moisture grains per cu. ft. at 62° F. and 30″ bar	Dust gr. per cu. ft. at 62° F. and 30″ bar	Efficiency as dust extractor
Top of furnace	5 to 6	500 to 600	35.0	14.00	...
Dry dust catcher	4.47	529	33.5	7.10	50%
Moyer washer	3.17	453	21.3	0.81	88.6
Stoves and boilers	3.17	453	21.3	0.81	...

With the water level lowered to from 2 inches to 3.5 inches below the central flue, the efficiency of the Moyer washer as a dust extractor was only about 75 percent, and it was even less efficient as an extractor of moisture. With the water levels at from 3.5 to 4.5 inches the efficiency apparently increased and was about the same as when tested with the 1.5 inch level. This washer used an excessive amount of water when compared with its low efficiency as a moisture extractor, the quantity of water averaging about 120 gallons per minute.

The efficiency of about 50 percent for the dry dust catcher was also very low, and this was probably due in a great measure to the location of the gas inlet, which was about four feet above the bottom, the entering gas thus continuously stirring up the precipitated dust and not permitting it to settle. The high moisture content in the gas coming from the Moyer washer was probably due to the high gas temperature, thus plainly pointing out the fact that a washer of the Moyer type cannot reduce the temperature sufficiently by impingement alone.

As there are no moving parts at Clairton the cost of water is the only item to be considered; with water at $10.00 per million gallons the washing of the gas, less labor, costs about 28.33 cents per 100,000 cubic feet. It will be noted that this plant only cleaned the gas for use in the hot-blast stoves and boilers, and not for engine purposes.

The first gas engine installation of any importance erected in America for the consumption of blast-furnace gas, was for the Lackawanna Steel Company at

Buffalo. — This cleaning plant was very inadequate, and a great many alterations were required before the apparatus reached any marked degree of efficiency, and while the plant is not an exhibit of modern practice, its description is of interest due to its historical character and in order to show the development in American practice.

In 1902 a gas engine plant of 40,000 horse power capacity was installed, and the accompanying cleaning plant, as altered, is shown in Figure 49, being located between two of the furnaces. Each furnace is provided with a separate cleaning plant, the two plants combining in common mains, and consisting of a dry dust catcher (*A*), four spray towers (*D*), four centrifugal fans (*E*) and four water separators (*F*). The gas from each furnace is delivered to the dry dust catcher (*A*) by a down-comer entering the catcher in the center at the top, the catcher being a simple cylindrical chamber with two outlet connections at the bottom, one of these being arranged to carry the gas to the stoves or boilers, and the other, marked (*B*), leading to the first spray tower.

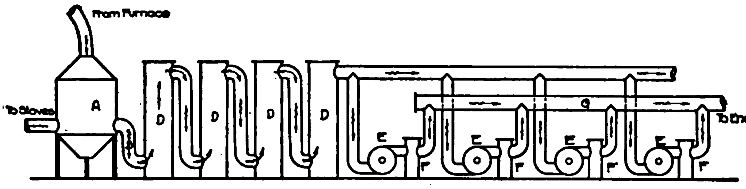


Diagram Through Plant

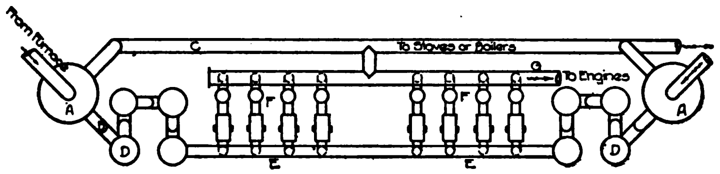


Figure 49. — Cleaning Plant at Buffalo

The towers are cylindrical shells provided with shelves to form compartments, while the water is sprayed in from the top through Koerting spray nozzles. After the gas has passed through the towers it is conducted by a common main to the fans, the latter also being supplied with water sprays. The water and its dust content is removed from the gas in the separators, after which the cleaned gas is conducted to either the engines through main (*G*), or to the hot-blast stoves and boilers through the main (*C*).

Edgar Thompson. — The general layout of this plant is shown in Figure 50, and consists of dry dust catchers, spray towers, fans, baffle washers, Zschocke washers, and Theisens. The first dry dust catcher (*A*) consists of a cylindrical chamber 20 feet in diameter by 35 feet high, receiving the gas from the down-comer at the top in the center, the gas leaving at about ten feet from the bottom, from whence it is conducted to the second dust catcher (*B*). The construction of this latter apparatus differs somewhat from the first one, being in the form of a horizontal cylinder ten feet in diameter by about twenty feet long, the bottom being provided with dust arresting bells; the gas enters at one end and is deflected downwards, leaving at the opposite end in an upward direction. The gas connections are so arranged at this outlet that the gas can be conducted to enter either the boilers and hot-blast stoves, or to the rough gas main (*C*) leading to the wet cleaning plant.

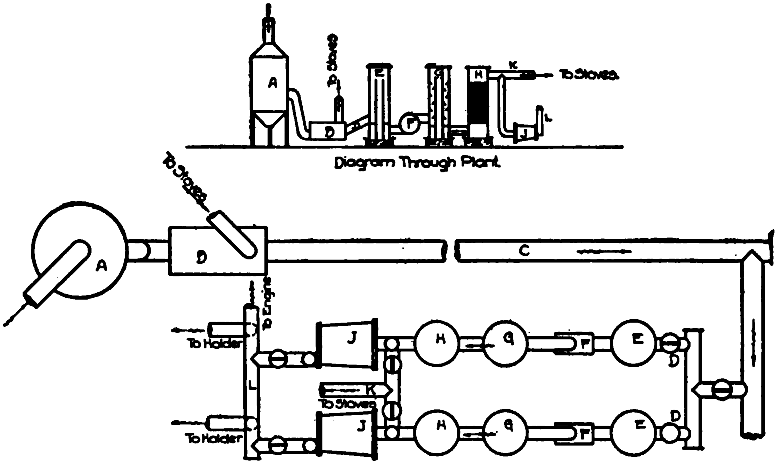


FIGURE 50.— Cleaning Plant at Edgar Thompson

The wet cleaning plant is arranged in duplicate, so connected that the apparatus can be operated in parallel, the usual method of operation, except during periods of repair, when one-half is shut down and the other half operated. The gas in main (*C*) is divided, one-half going through each of the two mains marked (*D*), from whence it enters the tower scrubbers (*E*). These towers are 10′ 6″ in diameter and 40 feet high, containing a central flue having a diameter of 4′ 6″; the gas enters at the bottom of the tower and passes upwards, descending to the bottom again through the central flue. The washer is provided at the top with a system of spray nozzles, the descending water spray meeting the ascending gas, while the bottom of the washer is open, the shell dipping into a water seal upon the surface of which the descending gas impinges.

Buffalo fans, marked (*F*), take the gas from the towers and deliver it into the bottom of the film washers marked (*G*); these washers are 10′ 6″ in diameter and 40 feet high, the gas ascending through the water film to the top, and then descending to the bottom through a central flue. The fans are water sprayed, operating at 800 revolutions and consuming 100 K. W. From the bottom of the film washers the gas is conducted into the bottom of the Zschocke washers marked (*H*), these latter devices also having open bottoms and sealing into a water pit; they are provided with thirteen sets of grids in a height of 40 feet, the towers having a diameter of 10′ 6″.

The gas is now conducted through the main (*K*) to the hot-blast stoves or boilers, or through the Theisen washers (*J*) and from thence through the clean gas main (*L*) to the engines. The dust laden water from the various towers is run into a settling basin about 40 feet square, the sludge being removed from here by means of a grab bucket attached to a locomotive crane.

The amount of water and power required in this plant is given in Table IX, but no account of the amount of water used in the fans is available, as this water is not used at all times.

TABLE IX. EDGAR THOMPSON PLANT

WATER AND POWER REQUIRED PER 1000 CUBIC FEET OF GAS CLEANED

Apparatus	Water required	Power consumed
Total towers	83 gallons	......
Fans	......	0.217 K. W. H.
Theisen washers	7.6 gallons	0.325 K. W. H.

Carrie Furnaces. — The apparatus used in this plant consists of two dry dust catchers (*A*), two impinging washers (*B*), six baffle washers (*C*), six fans (*D*), six Zschocke washers (*E*), and six Theisen washers (*F*), arranged for two furnaces, as shown in Figure 51. The gas from the furnace enters the top of the dry dust catcher (*A*) through the down-comer at the center, and leaves at the side very close to the top. The dry dust catchers are 35 feet in diameter and 20 feet high over the cylindrical shell, being nothing more than a simple settling chamber. From the dry dust catcher the gas is conducted to the top and center of the impinging washer (*B*), this washer having the same general dimensions as the dry dust catcher. The gas passes down through a central flue in the impinging washer and spreads out over the surface of the water in the bottom, this water being constantly kept at a level of a few inches below the lower edge of the central flue; a portion of the dust and a slight amount of heat is extracted here.

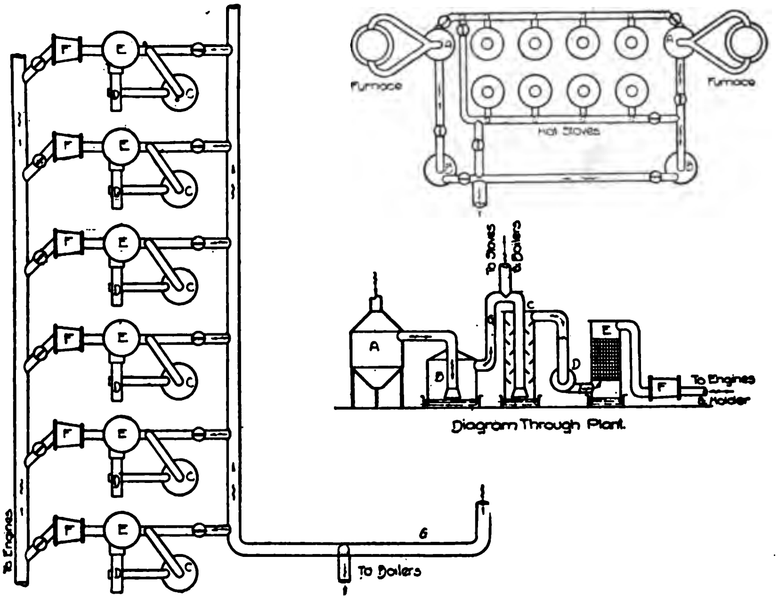


FIGURE 51. — Cleaning Plant at Carrie

When this washer was first installed water sprays were provided in the top, and the body was supplied with a series of grids of the Zschocke construction, the water trickling down over the grids and thus washing the ascending gas, the gas leaving the top of the device, but such an excessive amount of moisture was entrained in the gas by this procedure that it became necessary to abandon this spray system within a few days after the washer was placed in service.

The gas now enters the primary clean gas main (*G*), from whence it is conducted to the hot-blast stoves and boilers, or to the final cleaning plant. This main collects the gas from the primary cleaning plants serving eleven furnaces; it has a diameter of nine feet, and the bottom is provided with explosion or cleaning doors located about twenty-five feet apart. In the final cleaning plant the gas from main (*G*) first enters the baffle washers (*C*) through a water-sealed valve, coming in at the top and center of the washer and passing down to the bottom through a central flue, this flue having a diameter of five feet; the gas impinges upon the water in the bottom and then ascends, meeting a film of water which flows over a series of baffle plates. The washer is 15 feet in diameter and about 48 feet high, the top being provided with four 8 inch diameter water inlets, the bottom being open and the shell dipping into a water seal.

The gas is removed from the top of this washer by means of a fan, marked (*D*), ten feet in diameter, with blades about two feet wide. As long as the top pressure does not fall below three inches of water the fan is not used, as this pressure is sufficient to send the gas forward. The fan delivers the gas by means of tangentially located pipes to the Zschocke washer marked (*E*), this washer having a diameter of fifteen feet and a height of forty feet, being provided with thirteen sets of wooden grids and nineteen Koerting spray nozzles. The grids are made of one inch lumber dressed to 7/8″ thick, the spacing in the top set being one inch, and four inches in the bottom set, the spacing in the intermediate sets varying between these two figures. The bottom of the washer is open, the shell dipping into a water seal.

From the Zschocke washers the gas enters the Theisens, marked (*F*), each Theisen being about ten feet in diameter at the inlet end and nine feet in diameter at the outlet end and measuring fifteen feet between the center lines of inlet and outlet connections; from the Theisens the gas is delivered to the engines, a gas holder (*H*), not shown, acting as a safety supply device being shunted into this connection.

The operating results of this plant are shown in Table X.

TABLE X. CARRIE RESULTS

Apparatus	Pressure in water inches	Temperature in degrees F.	Moisture, grains per cu. ft. at 62° F. and 30″ bar	Dust, grains per cu. ft. at 62° F. and 30″ bar	Efficiency as dust extractor
Down-comer	11	420	..	....	...
Dry dust catcher	..	....	..	0.486	....
Impinging washer	..	....	..	0.324	33.3%
Rough gas main	7.5	255	..	....	....
Baffle washer	..	....	..	0.147	54.6%
Fan	..	81	..	....	....
Zschocke washer	..	....	..	0.083	44.0%
Theisen washer	15	....	..	0.010	88.0%
Clean gas main	..	66	9.5	....	....
Engines	4	....	..	....	....

The cost of operating this plant was excessive, a great amount of water being used, and the cost of labor being exceedingly high when compared with a properly designed plant.

During a test run made while four blowing engines were operating under 16 pounds pressure at 35 revolutions per minute, and two electric engines were each carrying an average load of 1250 K. W., it was found that 950,000 cubic feet of gas were being consumed per hour, the total indicated horse power of the six engines in use being 6800, showing a consumption of 139.7 cubic feet of gas per indicated horse power. Three units of the gas washing plant were sufficient to prepare the gas for this purpose, consequently each unit treated about 317,000 cubic feet of gas per hour. The velocity of the gas through the baffle washer was at the rate of 170 feet per minute, while it passed through the Zschocke washers at 56.5 feet per minute.

It was found by taking the channel through which the water flowed as a weir, and the depth of the water in the channel as the head upon the weir, and assuming a coefficient of 0,6, that the Zschocke washers were taking about 200 gallons of water per minute, and only cleaning 26.5 cubic feet of gas per gallon of water. Using the same method as above, it was found that the Theisens were receiving 33 gallons of water per minute, and cleaning 106 cubic feet per gallon. No arrangements were at hand to measure the amount of water being delivered to the baffle washer, but as this machine was being fed through an 8-inch pipe while the Zschocke was using a 6-inch pipe, the amount of water used was found by proportion to be about 350 gallons per minute, or at the rate of one gallon to every 15 cubic feet of gas cleaned.

The power required to operate the Theisens was 7.8 K. W. per 1000 cubic feet of gas passed.

Duquesne Furnaces. — At the Duquesne plant, furnaces No. 5 and No. 6 furnished the greater portion of the clean gas required, and the cleaning plant between these two furnaces is shown in Figure 52. The gas from each furnace passes through twin down-comers into the first dry dust catcher (*A*), and from thence into the second one (*B*), from these catchers the gas enters the rough gas main (*C*), and then passes on to the Duquesne scrubbers (*D*); from here the gas is conducted by means of main (*E*) to the fans (*F*) and separators (*G*), after which it is led into the hot-blast stoves and boilers through main (*H*), or to the Theisen washers (*J*) for final cleaning.

Both the primary and the secondary dry dust catchers (*A*) and (*B*) are of the centrifugal type, measuring 30 feet in diameter by 50 feet high, being connected in series. Of all the dust removed by a pair of these catchers, 85 percent is extracted in the first one, seeming to indicate that the second one might be dispensed with. The gas enters the catchers on the side in a tangential direction, and leaves centrally at the top, passing thence into the rough gas main (*C*) which is arranged to send the gas to the hot-blast stoves if desired. This main extends throughout the entire length of the blast-furnace plant, and is so connected to the furnaces as to make it possible to take gas from any of the furnaces and send it to the cleaning plant. This main has a diameter of 10′ 6″ and is provided at regular intervals with explosion and cleaning doors.

From the rough main the gas enters the bottom of the Duquesne towers (*D*), leaving them at the top. There are nine towers in the plant, each being 12′ 6″ in diameter and 87 feet high, the top being dome shaped. The water for spraying is admitted into the top of the tower and enters into a horizontally revolving spray, the gas ascending and coming into intimate contact with the falling water, the spray being as shown in detail in Figure 7. A screen of ½-inch wire mesh is located beneath the spray for the purpose of breaking up the helical sheet of water into drops, the water being supplied to these scrubbers by means of two Delavel centrifugal pumps, each of 5,000,000 gallons capacity per day at 1.5 pounds pressure through an 8-inch pipe, the sprays being rotated by a 5 horse power motor.

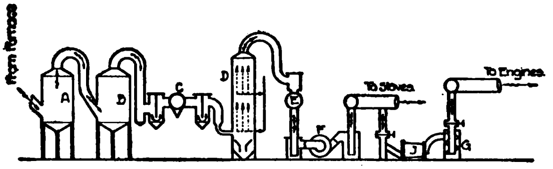


Diagram Through Plant

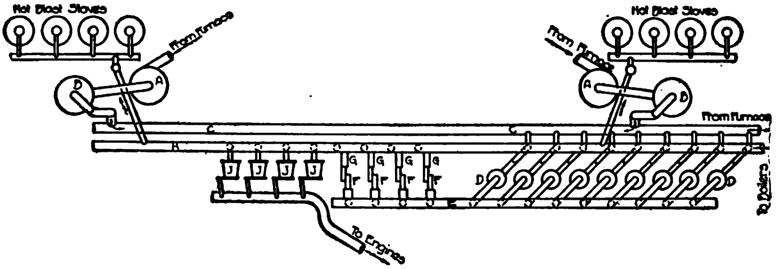


Figure 52.—Cleaning Plant at Duquesne

The gas passes through the tower at a velocity of 175 feet per minute when 31,000 cubic feet of gas per minute are treated. It has been stated that these towers are higher than necessary, and their use developed the new type of scrubber shown in Figure 9. The old type of scrubber necessitated shunting one off every few weeks in order to remove the accumulation of flue dust which had settled at the bottom, as an 8-inch diameter pipe was the only means supplied for carrying away the dust laden water. These scrubbers removed between 80 and 90 percent of the dust in the gas, the gas at the outlet containing from 0.1 to 0.15 grains per cubic foot; they required one gallon of water for every 38 cubic feet of gas cleaned, reduced to 62° F., or at the rate of 550 to 800 gallons of water per minute. The discharge water is run into a settling basin, from whence the sludge is removed by means of a grab bucket attached to an overhead crane.

The gas is next conducted to the four fans, connected in multiple, through a pipe 8′ 8″ in diameter; these fans were formerly used to force the gas through the separators into the clean gas main, but instead of boosting the gas they actually consumed one inch of water pressure unless operated at excessive speed; in consequence the rotors were removed from the fans, and the gas now merely passes through the casing. During operation these fans each required 220 gallons of water per minute, or one gallon for every 145 cubic feet of gas, but in consequence they reduced the dust content down to 0.02 to 0.03 grain per cubic foot, 150 horse power being required per fan when handling 32,000 cubic feet of gas per minute.

From the fans the gas enters the separators, where the entrained moisture is removed. This device consists of a vertical flue surrounded by a two-turn helical plate in a casing. The gas enters at the top, passes down around the helix and then up and out through the central flue, the water being thrown out to the side of the casing and descending to the bottom, from whence it is drawn off; the gas entering the separator has an average saturation above 40 percent, and leaves at about 2 percent above the point of saturation at the outlet temperature. The separators are 5 feet in diameter and 8 feet high. From the separators the gas is conducted to the Theisens, which are of standard construction, six of them being in use and requiring 150 horse power each.

Quite some extended data is at hand covering this plant, with the above described apparatus, as follows:

DATA ON DUQUESNE CLEANING PLANT

Coke used per ton of iron	2,256 lbs.
Stone used per ton of iron	1,118 lbs.
Air used per pound of coke	60.82 cu. ft.
Gas produced at 62° F. per ton of iron	156,000 cu. ft.
Gas at 62° F. used in stoves per minute	4,170 cu. ft.
Gas at 62° F. used in boilers per minute	33,010 cu. ft.
Gas at 62° F. going to scrubbers per minute	31,365 cu. ft.

Heat of gas per cubic foot at 62° F.	93.7 B. T. U.
Temperature of gas at furnace top	450.0° F.
“ “ “ before scrubber	343.3° F.
“ “ “ after scrubber	57.7° F.
“ “ “ at inlet to fan	55.8° F.
“ “ “ “ top of separator	54.9° F.
“ “ inlet water to scrubber	47.6° F.
“ “ outlet water from scrubber	90.2° F.
Dust in raw gas before dry dust catcher at 62° F. per cu. ft.	2.660 gr.
“ “ “ “ entering scrubbers at 62° F. per cu. ft.	0.137 gr.
“ “ “ “ leaving scrubbers at 62° F. per cu. ft.	0.023 gr.
Moisture in rough gas, per cu. ft.	27.90 gr.
“ “ gas leaving scrubbers per cu. ft.	7.86 gr.
“ “ “ “ separator per cu. ft.	5.50 gr.
Water used in each scrubber per minute, in gallons	810
“ “ “ “ fan per minute, in gallons	225
“ “ “ “ Theisen per minute, in gallons	35

Data on Plant Efficiency

Boilers on rough gas, 250 H. P. units at 330 H. P.	51 %
“ “ clean gas, 250 H. P. units at 330 H. P.	64 %
Stoves on dirty gas	56 %
“ “ clean gas	62 %
(Stoves on clean gas have an increased blast temperature of 150° F.)	
Scrubber as dust extractor	96.6 %
“ “ heat extractor	85.1 %
Fans as dust extractor	94.9 %
Efficiency of complete plant as dust extractor	99.1 %
Boiler H. P. per ton of iron per day	14.7 %
Cubic feet of gas per boiler H. P. hour at 94 B. T. U. per cubic foot and at 62° F.	514

At the time this test was made the air per ton was determined by the piston displacement of the blowing engines, assuming a delivery efficiency of 100 percent, but the actual efficiency was between 88 and 92 percent. The gas produced per ton of iron was calculated from the charge, the analysis of the iron and cinder, and the volumetric analysis of the gas, using carbon as the base of the calculation, because all of the carbon charged to the furnace leaves through the pig iron, cinder, or gas.

The amount of gas going to the hot-blast stoves, to the boilers, and to the scrubbers was measured with Pitot tubes, the open ends of the tubes being placed one-third of the way into the center of the pipe; while the heat value of the gas was determined by means of a Sargent gas calorimeter, then checked by a gas analysis and an allowance made for moisture. Both the amount of dirt and of moisture in the gas was determined with a Brady apparatus, which consisted of a $\frac{3}{4}$-inch diameter brass pipe, bent through 90 degrees, and inserted into the gas main in such manner that the open end of the pipe faced the flow of the gas; the gas and dirt both pass through the pipe into a cylinder the inlet of which is closed by means of a cup shaped filter paper. The dust is retained in the filter paper cup, while the gas passes into the cylinder and out to the air through a tube containing calcium-chloride which absorbs the moisture, while the gas is metered through a set type meter placed beyond the chloride tube.

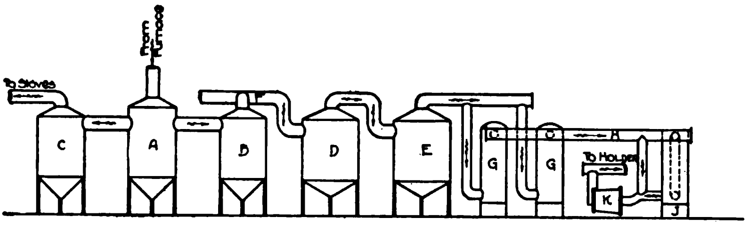


Diagram Through Plant

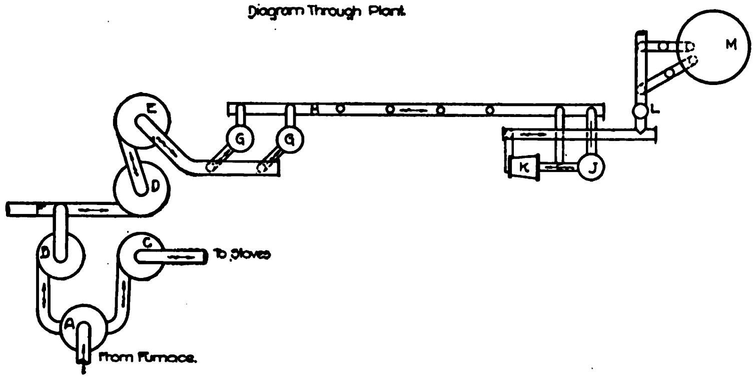


FIGURE 53. — Cleaning Plant at McKeesport

The water used was measured by means of weirs, and the boiler efficiencies by gas measurement and evaporation tests. Stove efficiencies were determined by measuring the gas supplied, its dust and moisture content, and by analysis, thus securing the total heat supplied, as well as the increase in temperature, moisture content, and quantity of air heated, especial care being taken to have the blast temperature the same at both the starting and the stopping of the test, and the ratio of the heat extracted to the heat supplied was taken as the measure of efficiency.

The McKeesport Plant. — At the McKeesport plant the gas from the down-comer enters at the top and center of the dry settling chamber (*A*), Figure 53, this chamber being 25 feet in diameter and 40 feet high, provided with two outlets situated 180 degrees apart, located at the side and close to the top of the shell, one of the outlets leading to the second settling chamber (*B*), and the other to a similar chamber (*C*), entering these settlers at the side and leaving at the top and center; both settling chambers (*B*) and (*C*) have a diameter of 25 feet and a height of 35 feet; chamber (*B*) delivers the gas to the rough gas main (*F*), which is connected to all of the furnaces, while chamber (*C*) delivers gas to the hot-blast stoves.

From the rough gas main (*F*) the gas enters a centrifugal dust catcher (*D*), measuring 35 feet in diameter and 35 feet high at the side, leaving at the top and center and entering a second catcher (*E*) of the same dimensions. The connection leading from the top of this second catcher connects to two Zschocke towers, each 14 feet in diameter and 40 feet high, connected in series. The gas from these towers enters a hydraulic main (*H*), from whence it is delivered to either another Zschocke tower (*J*) and from thence to the Theisen washer (*K*), or the tower may be by-passed and the gas sent directly into the Theisen.

After passing through the Theisen, the gas enters a baffle separator (*L*) and from thence into the gas holder (*M*), the engines being supplied from this holder. The gas passes through the Zschocke towers at a speed of about 175 feet per minute, and these towers require about 65 gallons of water per 1000 cubic feet of gas, and the Theisen washer requires about 65 K. W. for its operation. The gas holder has a capacity of 50,000 cubic feet, or sufficient gas to supply the engines for about 3.5 minutes.

The operating results at this plant are given in Table XI.

TABLE XI. McKEESPORT RESULTS

Apparatus	Pressure in water inches	Temperature in degrees F.	Moisture, grains per cu. ft. at 62° F. and 30″ bar	Dust, grains per cu. ft. at 62° F. and 30″ bar	Efficiency as dust extractor
Rough main	..	482	41.72	6.67	....
First centrifugal ..	..	446	51.44	2.11	68.4%
Second centrifugal.	..	334	33.65	1.49	29.4%
Zschocke washer ..	..	81	12.68	0.371	75.1%
Theisen washer....	16	80	10.90	0.183	50.7%

It will be noted that the efficiency of the Theisen during this test was very low, only being about 51 percent, and that the gas carried as much as 0.18 grain of dust per cubic foot to the engines.

It was stated that this plant required 1,500,000 gallons of water per day; if then, as stated before, 50,000 cubic feet of gas in the holder were sufficient to serve the engines for 3.5 minutes, about 855,000 cubic feet were required per hour, and as the water consumption amounted to 62,500 gallons per hour, one gallon of water was required for $\frac{855,000}{62,500} = 13.6$ cubic feet of gas, or 73.5 gallons per 1000 cubic feet of gas, an excessive quantity of water for the low efficiency given in the test.

Steelton. — The plant at Steelton is shown in Figure 54, and consists of a centrifugal dust catcher, two spray towers, and a Theisen washer. The gas from the down-comer enters the centrigufal dust catcher (*A*), this catcher having a diameter of 35 feet, and leaves it at the top and center, thence entering the two spray towers (*B*) and (*C*), each 25 feet in diameter and 60 feet high; from the towers the gas is conducted to the Theisen washer. The spray towers are so connected that they can be operated either in series or in parallel, and the outlets are so arranged that the gas can be sent to either the Theisen washer, or to the hot-blast stoves and boilers; the towers may also be by-passed and the gas sent direct to the stoves or boilers, all valves being water sealed.

The gas enters the spray towers through a brick-lined connection, the mouth of the pipe being turned down inside the tower so as to cause the gas to impinge upon the surface of the water in the bottom of the tower; the ascending gas is sprayed with water by means of the device shown in Figure 8.

In order to keep the temperature of the gas as high as possible until it reaches the spray towers, and thus prevent condensation in the centrifugal catcher and pipe connections, both the connections and the catcher are lined with brick; when the hot gas impinges upon the surface of the water in the tower, a portion of its heat is given up in evaporating water, and which water is later condensed by contact with the spray coming from above, the object of this method of operation being to ensure a thorough wetting and weighing down of the dust particles, this being accomplished by the condensation of the vapor, as by evaporation and subsequent condensation the water particles are of much smaller size than the dust particles, and the condensed particles of water have a better opportunity to surround and wet the dust than would the spray alone.

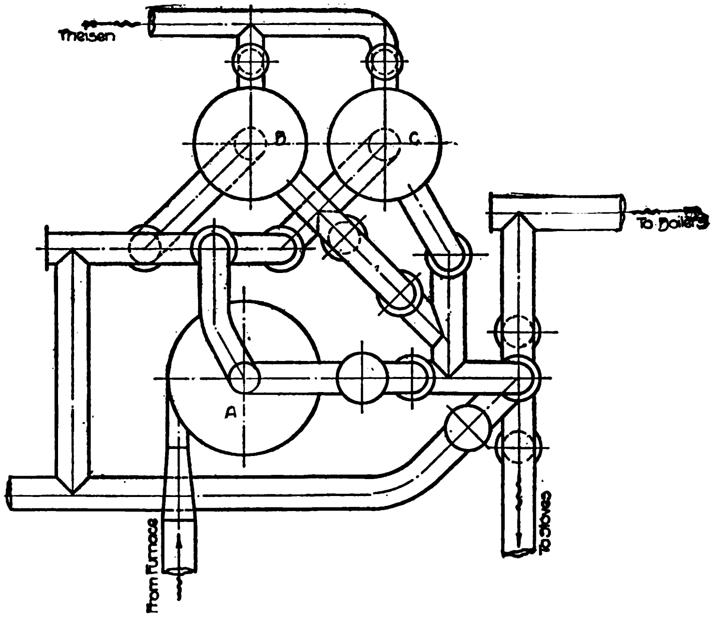


FIGURE 54. — Cleaning Plant at Steelton

This principle finds its most efficient application in the Feld, and other washers of its type.

Operating these two scrubbers in series brought about the following results during two test runs:

Dust at inlet	Dust at outlet	Efficiency
	SCRUBBER No. 1	
5.59 grains	0.641 grain	90.2 %
4.54 grains	0.593 grain	86.9 %
	SCRUBBER No. 2	
0.641 grain	0.144 grain	77.6 %
0.593 grain	0.109 grain	81.6 %

The dust content in grains per cubic foot was measured at 62° F. and 29.96″ barometer, while 26 gallons of water having an inlet temperature of 95° F. were used per 1000 cubic feet of gas, the gas leaving the scrubbers with a temperature of 105° F.

Gary. — The Gary plant is shown diagrammatically in Figure 55 as applied to furnaces Nos. 9 to 12 inclusive; in this plant two down-comers take the gas from the top of the furnace at four different points and deliver it tangentially to a dry dust chamber (*A*), 25 feet in diameter and 40 feet high, at a point located about one-third the height above the bottom of the shell. The gas leaves this catcher at the top and center and enters a second dust catcher (*B*), 18′ 6″ in diameter and 30 feet high; from this second catcher the gas enters a main, common to two furnaces, and is thereby delivered to three impinging washers (*C*) of the Mullen type.

One set of outlets from the impinging washers enters into a common collecting main (*D*) which supplies gas to the hot-blast stoves, and another set enters into a rough gas main (*E*) which is common to all furnaces; from this latter main the gas is led into the bottom of the scrubbing towers (*F*), sixteen towers being provided for eight furnaces, each tower being 18 feet in diameter and 60 feet high; an outlet near the top of the towers carries the gas to the Theisen washers (*G*), and from thence it is conducted to the engines. The scrubbing towers are a combination of baffle scrubber and spray washer, the lower portion being arranged as the baffle and the upper portion as a Zschocke tower.

South Chicago. — The South Chicago plant of the Illinois Steel Company serves six furnaces, divided into three groups of two furnaces each, each of these groups being provided with three dry dust catchers, as shown in Figure 56. The gas from each furnace down-comer is discharged into one of the outer dry catchers, both of these then delivering the gas into the central dry catcher of the group, from whence it enters the rough gas main extending throughout the entire length of the cleaning plant and forming a common connection for the six furnaces; the pipe connections to the dry dust catchers are provided with water-sealed valves so located as to cut off any furnace from the cleaning system when desired.

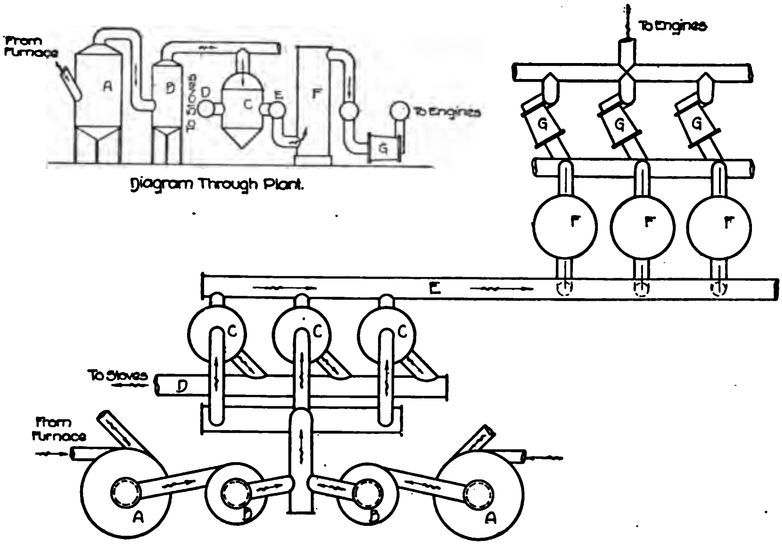


FIGURE 55. — Cleaning Plant at Gary

As the entire cleaning plant has been the subject of several additions, the various devices vary somewhat, and the dry dust catchers are not all of the same dimensions or construction; furnaces No. 1 to No. 4, inclusive, are supplied with two groups of three catchers, each outer catcher, or the one directly connected to the furnace through the down-comer, having a diameter of about 18 feet, the central one being about 40 feet in diameter; the catchers in the two groups of three catchers each attached to furnaces No. 5 and No. 6 each have a diameter of about 28′ 6″.

The gas from the down-comer enters a zigzag flue about six feet in diameter, this flue leading tangentially to the catcher, while the gas from the central catcher leaves at the top and enters the rough gas main which supplies the hot-blast stoves and boilers. The gas which is to be subjected to a final cleaning is taken off from the rough gas main at a point midway between furnaces No. 2 and No. 3, and is conducted to four tower scrubbers of the Zschocke type through a main 6′ 6″ in diameter. These towers are 22 feet in diameter and have a height of about 55 feet, being divided into six compartments each of which is provided with eight layers of slat trays, the individual slats being made of white pine dressed to 5″ × $\frac{7}{8}$″; each tower is supplied with thirty-six sprinklers of an original design, the water in each sprinkler falling through a distance of about eight feet and impinging upon a cast iron spray plate, so arranged as to break up the water

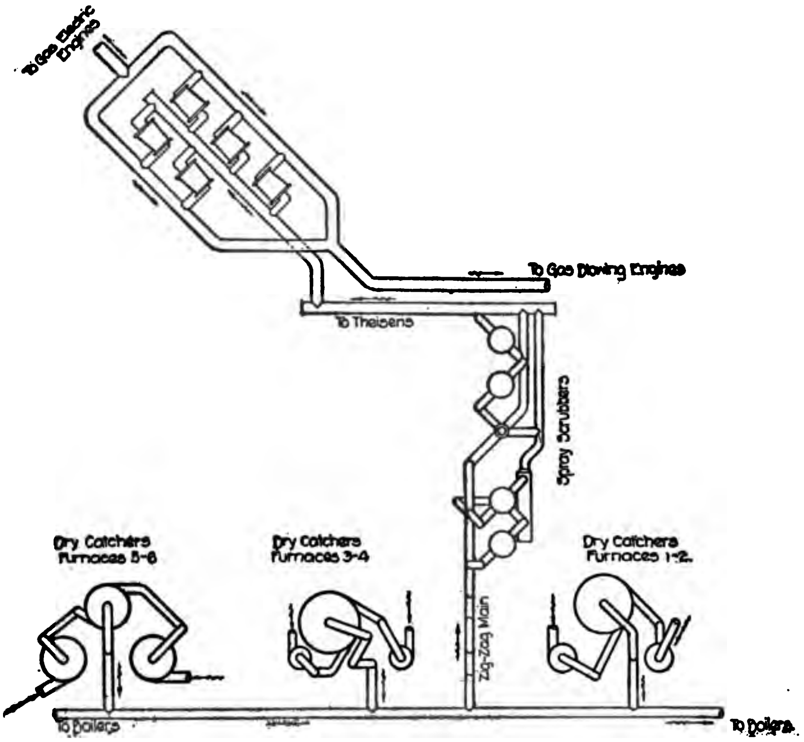


FIGURE 56.—Cleaning Plant at South Chicago

into a very fine spray and, as the individual sprinklers are so located as to overlap each other, the entire area of the scrubber is filled with water spray.

The lower shell of each tower terminates in a frustum of a cone, the lower edge of the sheet dipping into a concrete seal pit, this pit being provided with an overflow syphon extending on an incline down to the lowest point of the pit, the entering gas impinging upon the surface of the seal water before it rises in the tower. The gas connections around the tower are so arranged as to permit of operating all of the towers in series, in parallel, or in two groups of two towers each either in series or in parallel; operating results seem to point to the fact that the best washing effects are secured with the four towers connected in parallel.

From the towers the gas is conducted to five Theisen washers, each washer having a capacity of 15,000 cubic feet of gas per minute. The gas from the Theisens is taken off in two directions, one line leading to the gas blower engine house, and the other to the gas electric engine house, both terminals being provided with a gas holder of 100,000 cubic feet capacity, a water separator being interposed between the Theisen outlet and the gas holder on the gas blowing engine side, both lines being connected to a Venturi meter.

The operating results at this plant are given in Table XII.

TABLE XII. SOUTH CHICAGO

RESULTS

Apparatus	Average temperature in degrees F.		Moisture in gas in grains per cubic foot	Dust in gas in grains per cubic foot	Efficiency as dust extractor
	Gas	Water			
Down-comer	425	. .	...	....	.....
Before wet scrubbers	200	. .	...	1.200	.....
Before Theisens ...	75	. .	5.62	0.318	73.5 %
After Theisens	...	. .	...	0.006	98.1 %
Water supply	...	65	...	....	.....
Outlet Scrubber No. 1	...	80	...	....	.....
Outlet Scrubber No. 2	...	70	...	....	....

CONCLUSIONS

An examination of the principal plants operating in America shows that they are all designed to accomplish perfect gas cleaning in three distinct stages; viz.: first, the dry dust stage, depending upon settling action, induced by decreased velocity in chambers of large area, or where centrifugal motion and force is depended upon to carry and deposit the heavy particles out of the path of gas flow; second, the stationary wet stage, where water is used to entrain the dust particles by thoroughly wetting and weighting them, and thus removing them from the path of gas flow; no mechanical force is as a rule expended at this stage other than the power required to pump the water to its point of delivery but, as explained above, various methods have been adopted to accomplish this second result in several different styles of apparatus; third, the final stage, in which a rotary scrubber, usually a Theisen washer, is employed to remove the final particles of dust by producing a most intimate contact between gas and water and thus completely entraining the remaining dust.

Of the two types of dry dust catcher it would seem that the centrifugal is much more effective as a dust extractor than is the simple settling chamber, and the results obtained at the McKeesport plant seem to point out this fact very strongly, because here we find a single large dust settling chamber followed by a small centrifugal catcher; but owing to the small dimensions of the centrifugal the velocity of the gas is too high to permit of efficient dust extraction, as the gas, after having passed through the settling chamber and subsequent centrifugal catcher, still contained a considerable quantity of dust. From here the gas passes into two large centrifugal catchers, where almost eighty percent of the dust is removed, the gas going to the wet scrubbers containing on an average of about 1.5 grains of dust per cubic foot, while it left the small centrifugal with a dust burden of about seven grains per cubic foot. This same result has been experienced at other plants where both settling chambers and centrifugal catchers were employed.

The second stage, or the static scrubber stage, is the one where the greatest differences occur, both in the design and construction of the apparatus and in the results secured. At Duquesne we find towers having a very great height in proportion to their diameter, while at other plants this comparative height is greatly reduced; at Carrie we find both baffle and Zschocke washers; at McKeesport we find Zschockes, at Gary impinging washers and towers, at Steelton towers only are used, and so on through all of the plants, hardly two of them being uniform in design, all having been subject to the individual experience of the designer.

The towers originally placed in the Duquesne plant were found to be much higher than necessary and the new ones will be constructed with a lesser height; again, we find it stated at McKeesport that a single Zschocke scrubber is sufficient to prepare the gas for the Theisen, but it must be remembered in this case that the gas passes through two centrifugal catchers before it enters the tower, its dust content being thereby materially decreased; and at Carrie it is said that the baffle washer is sufficient to prepare the gas for the Theisens, but here again we find that the gas passed through an impinging washer after leaving the dust catcher and before entering the towers. This odd assortment of apparatus and lack of uniformity in design does not give much data which can be utilized for constructive purposes.

In general, the number of scrubbers required depends entirely upon the quantity and character of the gas to be treated, but as a general rule they should be as few in number as is consistent with the degree of cleanliness required for securing the maximum efficiency in the final rotary washers, because the greater the number of scrubbers installed the greater will be the resistance offered to the passage of the gas, this fact in turn requiring a greater power output at the fans, or exhausters, to overcome this resistance and deliver the gas to the point of consumption with a pressure sufficiently high to accomplish the desired results. At some plants, such as Duquesne, fans were found unnecessary, as the loss in pressure during passage through the preceding apparatus was not of enough moment to require this additional expenditure of power, and at the Carrie plant the fans are only operated when the pressure in the rough gas mains drops below three inches of water; McKeesport required no fans at all, while it seems that they must be used at the Edgar

Thompson works, and the various plants all vary in some such particular.

A close study of these conditions at the various plants seems to point to the fact that if only one scrubber is made the unit, no fans will be required, while two scrubbers in series will occasionally require the assistance of a fan, and three scrubbers in series will almost always require this additional apparatus, this condition pointing to the necessity of so designing the cleaning plant that, commensurate with efficient cooling and cleaning, no more apparatus be installed than is required to accomplish the desired result, and in selecting the individual devices those which give a minimum of back pressure should be used, thus obviating the necessity of fans or, if they must be used, they should not be called upon to consume more power than the proper design of the preceding apparatus would call for.

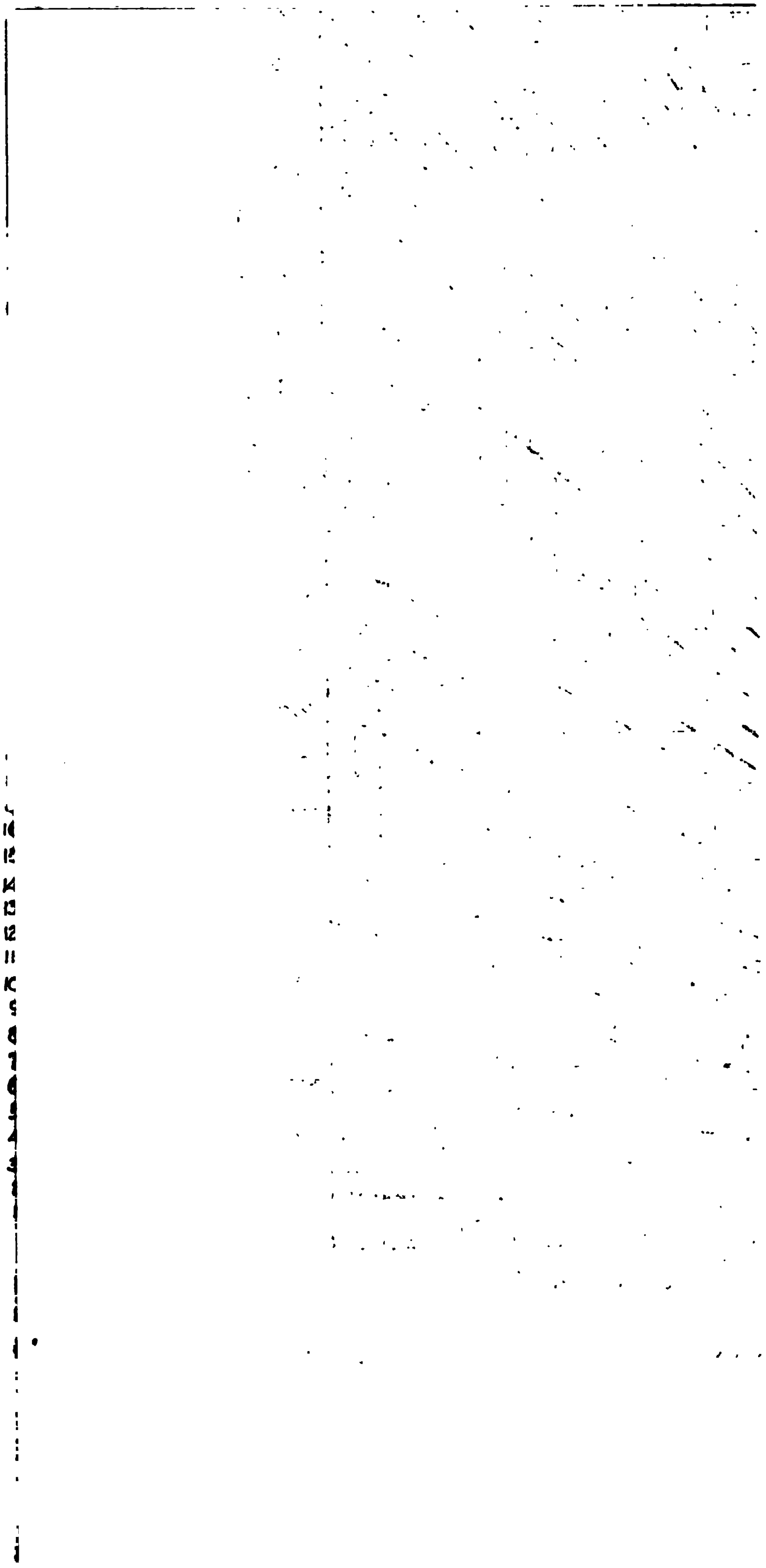
Diagram VI gives the power required to operate fans, or exhausters, for various quantities of gas and various back pressures, the latter expressed in mm. of water; the increased power required by a small increase in back pressure can readily be seen on this diagram.

DIAGRAM VI. EXHAUSTER POWER DIAGRAM

CUBIC FEET OF GAS AT VARIOUS TEMPERATURES

No.	0° C. = 32° F.	25° C. = 77° F.	65° C. = 150° F.	No.	0° C. = 32° F.	25° C. =77° F.	65° C. = 150° F.
100	1,050,000	1,106,000	1,722,000	1700	17,850,000	18,802,000	29,274,000
200	2,100,000	2,212,000	3,444,000	1800	18,900,000	19,908,000	30,996,000
300	3,150,000	3,318,000	5,166,000	1900	19,950,000	21,014,000	32,718,000
400	4,200,000	4,424,000	6,888,000	2000	21,000,000	22,120,000	34,440,000
500	5,250,000	5,530,000	8,610,000	2100	22,050,000	23,226,000	36,162,000
600	6,300,000	6,636,000	10,332,000	2200	23,100,000	24,332,000	37,884,000
700	7,350,000	7,742,000	12,054,000	2300	24,150,000	25,438,000	39,606,000
800	8,400,000	8,848,000	13,776,000	2400	25,200,000	26,544,000	41,328,000
900	9,450,000	9,954,000	15,498,000	2500	26,250,000	27,650,000	43,050,000
1000	10,500,000	11,060,000	17,220,000	2600	27,300,000	28,756,000	44,772,000
1100	11,550,000	12,166,000	18,942,000	2700	28,350,000	29,862,000	46,494,000
1200	12,600,000	13,272,000	20,664,000	2800	29,400,000	30,968,000	48,216,000
1300	13,650,000	14,378,000	22,386,000	2900	30,450,000	32,074,000	49,938,000
1400	14,700,000	15,484,000	24,108,000	3000	31,500,000	33,180,000	51,660,000
1500	15,750,000	16,590,000	25,830,000	3100	32,550,000	34,286,000	53,382,000
1600	16,800,000	17,696,000	27,552,000	3200	33,600,000	35,392,000	55,104,000

As stated before, the third, or final stage of cleaning in America is usually accomplished by means of the Theisen washer, and while this device has been, and is still, very effective in its dust extracting properties, it is a great consumer of power, and this latter fact has led to the design and



adoption in Europe of the Disintegrators of the Theisen and Schwarz-Bayer type, and vertical centrifugal washers of the Feld type; besides power cost, the cost of repairs is also a maximum with Theisen washers, and this latter additional cost makes quite an appreciable difference in the total cost of gas cleaning.

The amount of water used in the various American plants also varies greatly, and this difference seems to be due not only to the character of the gas itself, but also to the character and design of the apparatus used. Duquesne requires less water than either McKeesport, Edgar Thompson, or Carrie, but in all cases the amount used is in considerable excess of the theoretical requirement, proving that the towers are not nearly as efficient coolers as are machines of later design.

Some of the plants are either cleaning the gas to a greater degree than is required for hot-blast stoves and boilers, or water is being wasted in an improperly designed apparatus, but in order to secure some comparative data on the relative cost of cleaning gas in various plants and with different devices, Table XIII has been compiled with the amount of water actually used in the three American plants, but in the matter of the later European designs the theoretical quantity of water required to properly cool and clean the gas is used as a basis, as the low amounts of water claimed for some of the foreign devices would preclude proper cooling; the better spraying effect of these later type machines permits of better water distribution and gas contact, and hence better cooling effect, and for this reason the theoretical quantity of cooling water required has been used in making up the statement.

It will be noted that in the Theisen and in the Schwarz-Bayer disintegrators the pulverizing of the water is effected by means of disintegrating rods, while in the Reading and Stolte machines vanes are used for this purpose. Both of these constructions necessarily lead to power absorption, the amount used depending upon the volume of the injection water and upon the velocity of the revolving pulverizer. The disintegrator rods, as well as the vanes, operate within a confined space and against the almost inelastic water, seeming in design to be merely an improvement upon the old style fan with water injection which until quite recently was one of the usual means adopted to clean blast-furnace gas, but with excessive power consumption; besides this, the disintegrators maintain the same objection which was raised against the fan in that the gas is in contact with the water too short a time.

The forcing of the gas through the incompressible water in an apparatus such as this also causes considerable loss in pressure, and consequently the machines themselves are provided with fan blades, or an independent fan is used as the next step in the system in order to recover or to increase this gas pressure and thus to convey the gas to its point of consumption, this necessarily requiring additional power.

In washers of the Feld type this same condition does not exist, as the largest amount of power consumed in either the Feld or the Standard machine is only that required to pick up and pump the water through the spraying device, plus what is required to overcome the friction in the single antifriction bearing in the top; under these conditions a device such as this is of a superior design when considered as a power consuming machine, because the moving parts offer less resistance to the prime mover, and the effort to pulverize the water is minimized, which, combined with an efficiency equally as great as that of the disintegrator, makes the Feld type a superior device.

The only other consideration to be taken into account in selecting the type of rotary washer to be used, is the one governing its condensing or cooling qualities, or the one which can bring the gas into the most intimate contact with the cooling water without creating channels or short circuits which would permit the gas to pass through without proper water contact. Here the Feld and the Standard are again superior to the other verticals, because practically the entire inside of the chamber can be filled with fine water spray, this depth of spray depending upon the depth of the spraying device, but in the Standard device the bent tubes might be subjected to stoppages, while the cones in the Feld are perfectly capable of clearing themselves.

In such machines where horizontal plates are used for spraying purposes, there will always be a possibility of channeling, or short circuiting, and in order to prevent this, and to maintain the same depth of spray in the gas passages throughout the entire machine, it is necessary that these

TABLE XIII

COST OF CLEANING 100,000 CUBIC FEET OF GAS

System	Gas in million cu. ft.	Power K. W. H.	Water in million gallons	Labor men	Steam in thousand lbs.	Miscellaneous	Power cost	Water cost	Labor cost	Steam cost	Total cost	Cost per hundred thousand cu. ft. in cents
American No. 1	20.6	1,545	1.504	2	..	$2.50	$15.45	$15.04	$3.00	..	$35.99	17.47
American No. 2	45.2	13,704	2.880	3	..	2.50	137.04	28.80	4.50	..	172.84	38.23
American No. 3	22.8	2,868	2.526	7	..	2.50	28.68	25.26	10.50	..	66.94	29.36
Fowler & Medley	60.0	2,112	9.000	2	..	1.67	21.12	90.00	3.00	..	115.79	19.30
Theisen Disintegrators	42.0	5,014	1.063	2	..	1.67	50.14	10.63	3.00	..	65.44	15.58
Schwarz-Bayer	38.1	4,104	0.957	2	..	1.67	41.04	9.57	3.00	..	55.28	14.50
Halberger-Beth...........	25.4	1,880	0.018	4	16.00	5.63	18.80	0.18	6.00	$2.88	33.49	13.18
Halberger-Beth...........	40.7	2,688	0.030	4	25.55	8.00	26.88	0.30	6.00	4.60	45.78	11.25
Halberger-Beth...........	56.0	3,581	0.039	4	35.15	8.00	35.81	0.39	6.00	6.33	56.53	10.12
Feld, with fans	105.9	6,046	2.740	2	..	1.67	60.46	27.40	3.00	..	92.53	8.73
Feld, no fans.............	105.9	3,000	2.740	2	..	1.67	30.00	27.40	3.00	..	62.07	5.86

If the Theisen and the Schwarz-Bayer systems are figured with the amount of water consumption claimed, the cost would be:

System	Gas in million cu. ft.	Power K. W. H.	Water in million gallons	Labor men	Steam in thousand lbs.	Miscellaneous	Power cost	Water cost	Labor cost	Steam cost	Total cost	Cost per hundred thousand cu. ft. in cents
Theisen..................	42.0	5,014	0.175	2	..	1.67	50.14	1.75	3.00	..	56.56	13.46
Schwarz-Bayer	38.1	4,104	0.208	2	..	1.67	41.04	2.08	3.00	..	47.79	12.53

horizontal plates be perfectly level, otherwise more water will be thrown out on one side than on the other with a consequent difference in spray depth.

In making up the statement in Table XIII the cost of water was taken at $10.00 per million gallons, and power at one cent per K. W. H. Water for the European systems was taken at 25 gallons per thousand cubic feet of gas for cooling and cleaning; labor at $1.50 per man, and steam at eighteen cents per thousand pounds.

In figuring the cost of cleaning the gas with the Halberger-Beth system the builders usually deduct the value of the recovered dust, amounting to about $1.40 per ton; this was not done in preparing the tabular statement because the material recovered by the wet system is also of value, as witness the operations of the United States Steel Corporation cited in the preceding pages. In the three American systems given in the table, each system operates in the usual three stages, but with differently designed apparatus; it will also be seen that the one plant requires more men than any of the others.

In figuring the power requirements for the disintegrator systems nothing was added for the larger, or theoretical quantity of water required; the use of this larger volume of water would, however, add considerable power consumption to that given in the table.

The greatest difference in all of these systems lies in the power consumptions, as is seen in Table XIV.

TABLE XIV. POWER REQUIRED IN CLEANING SYSTEMS

System	Power per 1000 cubic feet of gas
American No. 1	0.075 K. W. H.
American No. 2	0.304 K. W. H.
American No. 3	0.126 K. W. H.
Fowler & Medley	0.0352 K. W. H.
Theisen disintegrators	0.119 K. W. H.
Schwarz-Bayer	0.108 K. W. H.
Halberger-Beth	0.064 to 0.074 K. W. H.
Feld, with Fans	0.057 K. W. H.
Feld, no Fans	0.0283 K. W. H.

CHAPTER VII

THE STORAGE OF GAS

The proper operation of the gas engine requires that the gas be delivered in constant quantity and at a uniform pressure, these two conditions being best complied with by the installation of a gas holder between the cleaning plant and the engine house. The holder need not be of very large capacity, but it should be of sufficient size to supply the engines for a period of thirty minutes, but even though this capacity be furnished, the holder should not be depended upon for an engine supply of more than fifteen minutes, this latter length of time being sufficient to allow of proper preparation for a necessary shut-down when the gas supply is suddenly discontinued.

A 1000 K. W. plant, operating with gas engines, should be provided with gas storage of about 100,000 cubic feet, and this capacity would about meet the above conditions, allowing 100 cubic feet of gas per K. W. The connection between the holder and the engines should be provided with an automatic governor for the purpose of regulating and maintaining the required operating pressure, this pressure being otherwise subject to fluctuations due to varying conditions of load.

The holder should be arranged in a manner similar to that shown in Figure 57, the inlet and outlet pipes being so located as to permit of sealing them off from the plant by filling them with water. The inlet pipe should also be provided with some form of automatic cut-off, or valve, operated by the holder proper, and so arranged as to remain open when the holder is being inflated by the entering gas up to a point slightly below the maximum rise of the bell, when the valve should be completely closed and thus cut off the entering gas.

This can best be accomplished by the installation of some form of butterfly valve in the vertical portion of the inlet pipe, the projecting shaft of the valve being provided with a lever whose fulcrum is attached to the upper portion of the guide frame; a weight suspended from the holder side of this lever opens the valve when gas is withdrawn from the holder and the bell descends; when the holder bell rises and reaches a point a few feet below its maximum rise the crown of the bell comes in contact with the weight and raises it, thus permitting the weight on the end of the valve lever to drop and close the valve.

The tank of the holder is filled with water, this water acting as a seal for the gas, and in order to prevent freezing the water must be heated, or rather warmed during the winter months. The steam injector, shown in Figure 58, is to be recommended for this purpose, its operation being explained in the diagram; this injector permits of proper heat regulation, which is very important, and it is necessary to take frequent temperature readings of the holder water. If the temperature of this water should be too high, moisture would be absorbed by the gas, this moisture condensing subsequently in the engine supply pipes where it would freeze and cause any amount of trouble. The injector shown in Figure 58 produces a surface circulation of the water, and under this condition it is not necessary to have the temperature of the water higher than 40° F., a higher degree of temperature, as stated above, being liable to disturb operating conditions.

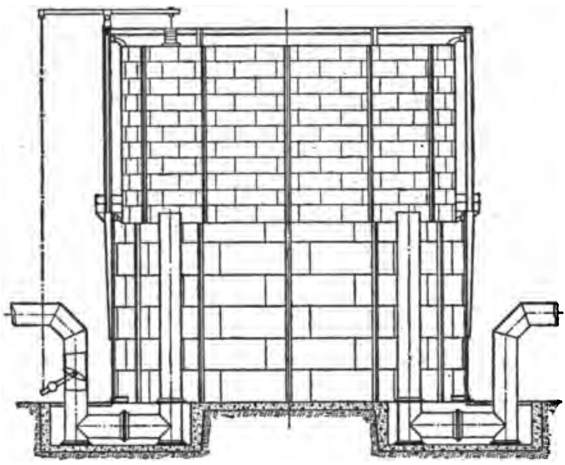


FIGURE 57. — Gas Holder

Proper automatic signals should be arranged between the engine room and the holder, so that the holder can give the engine attendant proper and timely warning when the supply is about to give out. These automatic signals should also notify the washing department of this condition, as a timely warning to this department may avoid many disagreeable results. In addition to these automatic signals it would be well to so locate the holder that its gas delivering possibilities are visible to both the engine and to the washer attendants.

If possible, the gas holder should be of a single lift construction, as a second lift will somewhat complicate the pressure regulation, but if the amount of storage required be such that the installation of a single lift holder would no longer be economical, a double lift holder should be supplied, and in this case the outer section should be so counterweighted as not to interfere with the predetermined operating pressure.

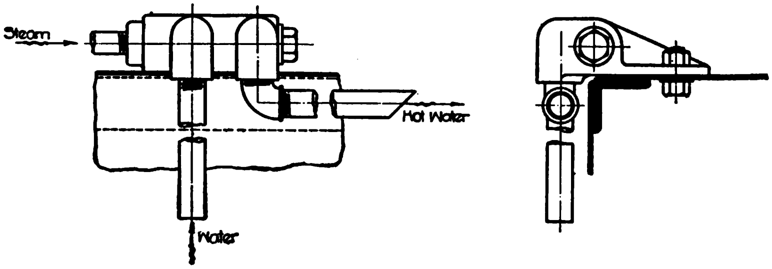


Figure 58.—Steam Heating Syphon

The structural shapes used in the construction of the holder, tank, and guide frame should be of open hearth steel, having an ultimate strength of from 50,000 to 65,000 pounds per square inch, while the material in the holder bell, except the heavier plates, should be of the best annealed gas holder iron; the heavier holder plates as well as those which are used in the tank should also be of steel containing high physical properties.

In designing the holder it is usual to proportion the guide frame to withstand a wind velocity of one hundred miles per hour against the tank filled with water and the holder filled with gas; this wind velocity will exert a pressure of 26 pounds per square foot upon the projected cylindrical area of the entire structure, the pressure on the holder bell being transmitted through the rollers to the guide frame, and this frame must be proportioned to resist this entire pressure. In addition to this wind load, a snow load of five pounds per square foot should be allowed on one-half of the crown area, the tilting force of this load also being transmitted to the guide frame.

All of the material entering the structure should be so proportioned that the maximum strains in any portion of the structure should not exceed 13,500 pounds per square inch in the net section of the material, and the maximum strain in the rivets should not exceed 8450 pounds per square inch for rivets in single shear, and 15,450 pounds for those in double shear.

All joints in both the tank and in the holder proper should be made metal to metal, no jointing material being used to make the joints tight, thus depending entirely upon caulking to prevent possible leaks.

The pressure thrown by the holder is usually expressed in inches of water column, and it is a product of the weight of the holder proper, its horizontal area, and the weight of the water column.

In order to determine the pressure thrown by the holder when it is fully inflated, let

R = the radius of the inner lift, in feet;
R_1 = the radius of the outer lift, in feet;
P_a = the air pressure thrown, expressed in inches of water column;
P_g = the gas pressure thrown, expressed in inches of water column;
W = the weight of the gas holder bell, or inner section, in pounds;
W_1 = the weight of the outer section, in pounds;
W_2 = the weight of the water contained in the cup of the inner section of a double lift holder, in pounds;
5.2 = the weight of water one inch high over an area of one square foot.

Then the air pressure for a single lift holder will be given by

$$Pa = \frac{W}{R^2 \pi \times 5.2}, \tag{14}$$

in which $R^2\pi \times 5.2$ is the weight corresponding to a water column one inch high; and the necessary holder weight required to produce a required pressure will be given by

$$W = P_a R^2 \pi \times 5.2, \tag{15}$$

the corresponding radius of the holder being given by

$$R = \sqrt{\frac{W}{P_a \pi \times 5.2}}. \tag{16}$$

If the holder should be of the double lift construction, the air pressure thrown by the two lifts, the outer section not being counterweighted, would be given by

$$P_a = \frac{W + W_1 + W_2}{R_1^2 \pi \times 5.2}, \tag{17}$$

and if a predetermined pressure must be maintained the outer section should be provided with sufficient counterweight to neutralize the additional pressure thrown by this section.

In order to determine the pressure thrown by the holder when it is inflated with gas, let

h = the height of the gas column in the holder expressed in feet;
s = the specific gravity of the gas, air being 1;
0.08073 = the weight of a cubic foot of air at sea level and at 32° F., expressed in pounds.

Then

$$P_g = P_a - \frac{h\,(0.08073 - s \times 0.08073)}{5.2}, \tag{18}$$

this pressure being given at the water overflow level in the tank.

The increase or decrease of pressure in closed vessels or containers filled with gas having a specific gravity which is less than that of air, expressed in inches of water column and at a temperature of 32° F., will be given by

$$\frac{0.08073 - s \times 0.08073}{5.2}$$

for each foot of height, and as the absolute temperature is at 491.4° F. below the freezing point, the volumetric coefficient of air or gas will be

$$\frac{1}{491.4} = 0.002035.$$

Since the weight of a cubic foot of air at sea level and at 32° F. is 0.08073 pound, the weight of a cubic foot of air at any temperature above the freezing point may be found when

N = the number of degrees F. above the freezing point at which the weight W of a cubic foot of air weighing 0.08073 pound at sea level, shall be determined.

Then

$$W = \frac{0.08073}{1 + (N - 32)\,0.002035}. \tag{19}$$

For example, the weight of a cubic foot of air at 60° F. will then be

$$W = \frac{0.08073}{1 + (60 - 32)\,0.002035} = \frac{0.08073}{1.05698} = 0.0764 \text{ pound.}$$

The use of this data permits of finding either the gas or air pressure of a holder under any condition of operation.

The actual pressure thrown by a holder will usually be found to be about 2 1/2 percent less than the theoretical figure, due to the fact that actual construction of the holder does not permit of maintaining the absolute figured weight.

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